Energy Modeling Activities at Berkeley Lab

presentation in ER220
Modeling Energy and Resource Systems

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by

Chris Marnay & Bala G Chandran

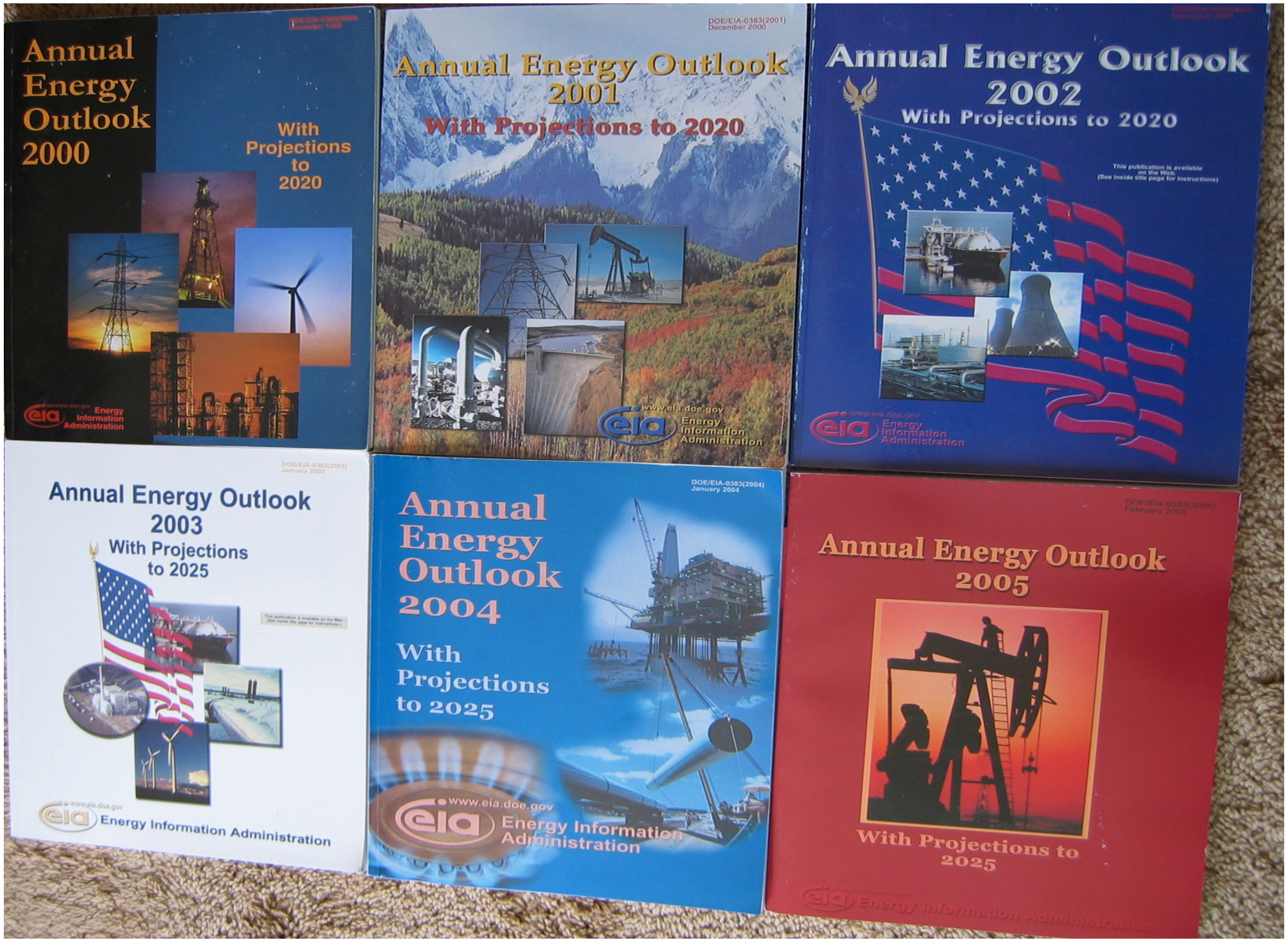
Berkeley Lab - C_Marnay@lbl.gov – tel: 510.486.7028
BGChandran@lbl.gov – tel: 510.486.4718

Outline

I. Introduction to the National Energy Modeling System (NEMS)
II. Selected NEMS 2006 Results
III. Introduction to the Government Performance and Results Act (GPRA)
IV. Distributed Energy Resources (DER) in NEMS
V. Residential Electricity Demand Forecast Disaggregation
VI. Developing an Electricity Market Module (EMM) Power Flow Layer
VII. Uncertainty in NEMS
VIII. Stochastic Energy Deployment System (SEDS)

I. Introduction to NEMS

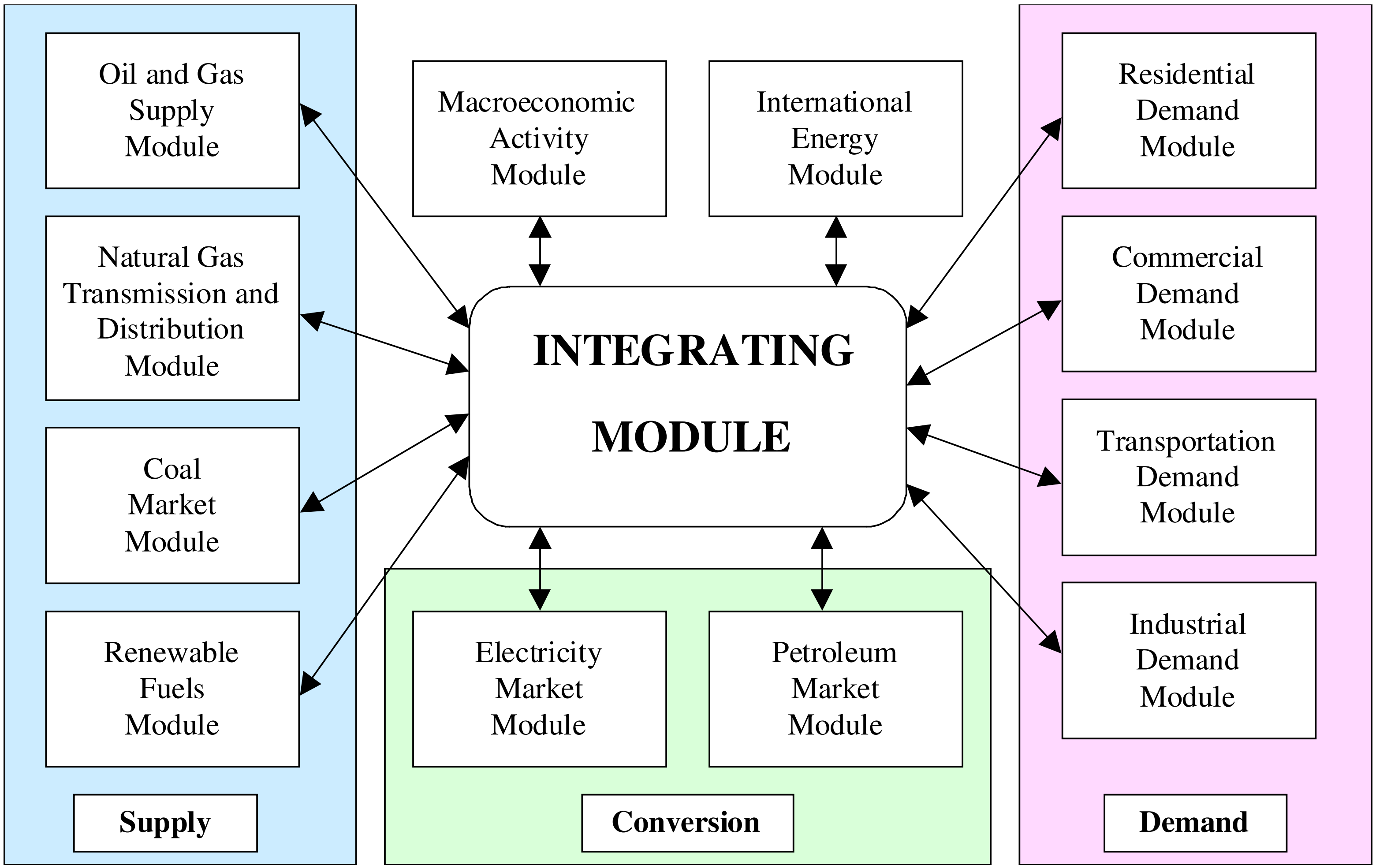
Annual Energy Outlook



Basics

- Annual Energy Outlook is a NEMS run
- forecast of entire U.S. energy sector to 2030
- "NEMS" is the EIA official version
- huge and impenetrable FORTRAN code
- broad reach provides illuminating view
- widely understood if not widely used
- common starting point for policy discussions
- Berkeley Lab has maintained the latest full blown version for about 10 years
- is used in APS, GPRA, PBA (scenarios, power flow …)
- other applications likely

The National Energy Modeling System (NEMS)



Limitations of NEMS

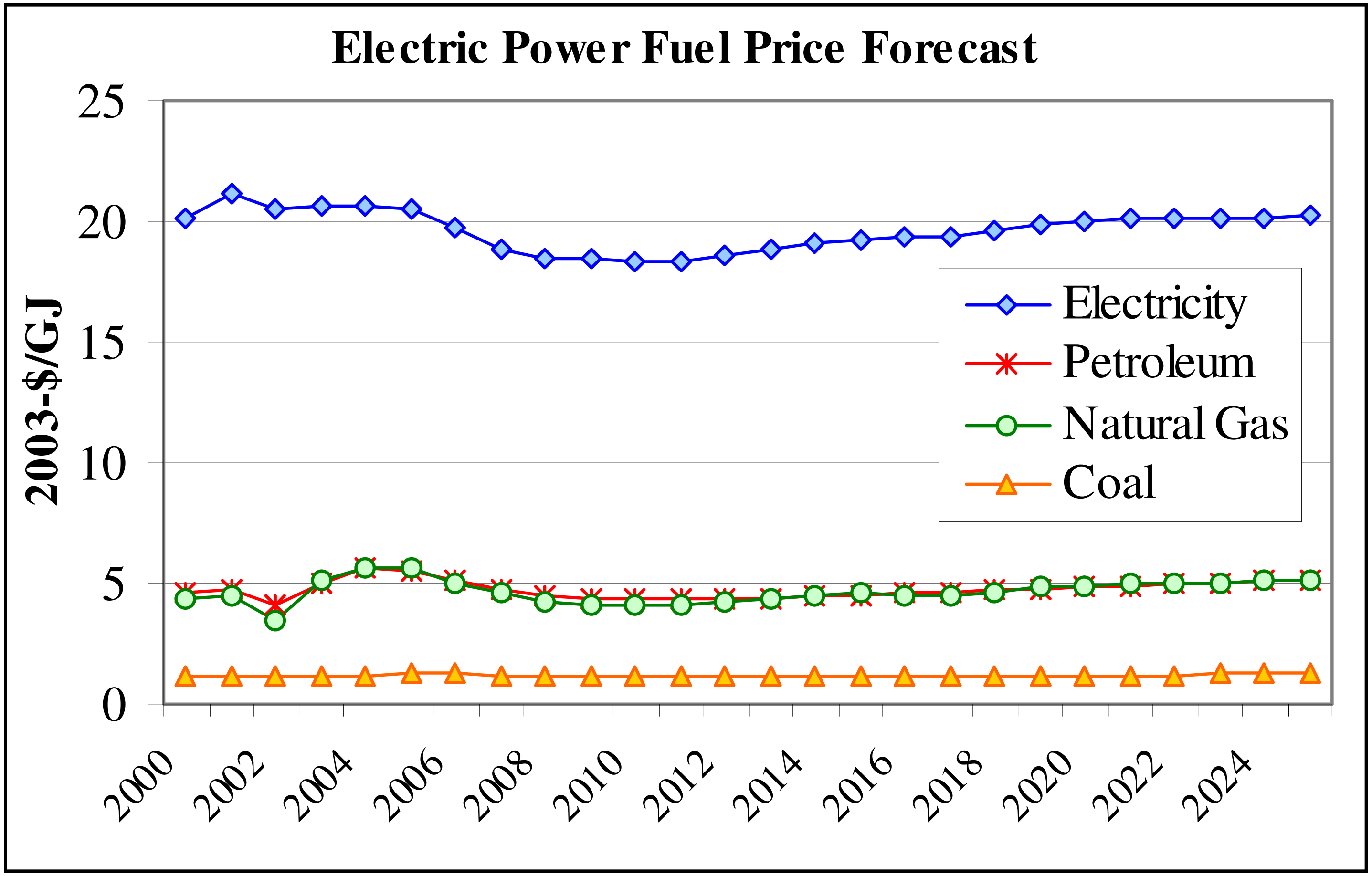
- significant computational time & power (6+ h run time)
- learning curve is long and steep
- one official version, with some "side cases"
- data driven model with high inertia
- inconsistent modules & inputs (e.g. regional defs.)
- extreme sensitivities crash model (or worse)
- need for carefully crafted cases
- AEO treadmill
- complicated model poorly suited for comprehensive sensitivity analysis
- hopeless for analysis of uncertainty
  - scenarios, SEDS

Our Work Using NEMS

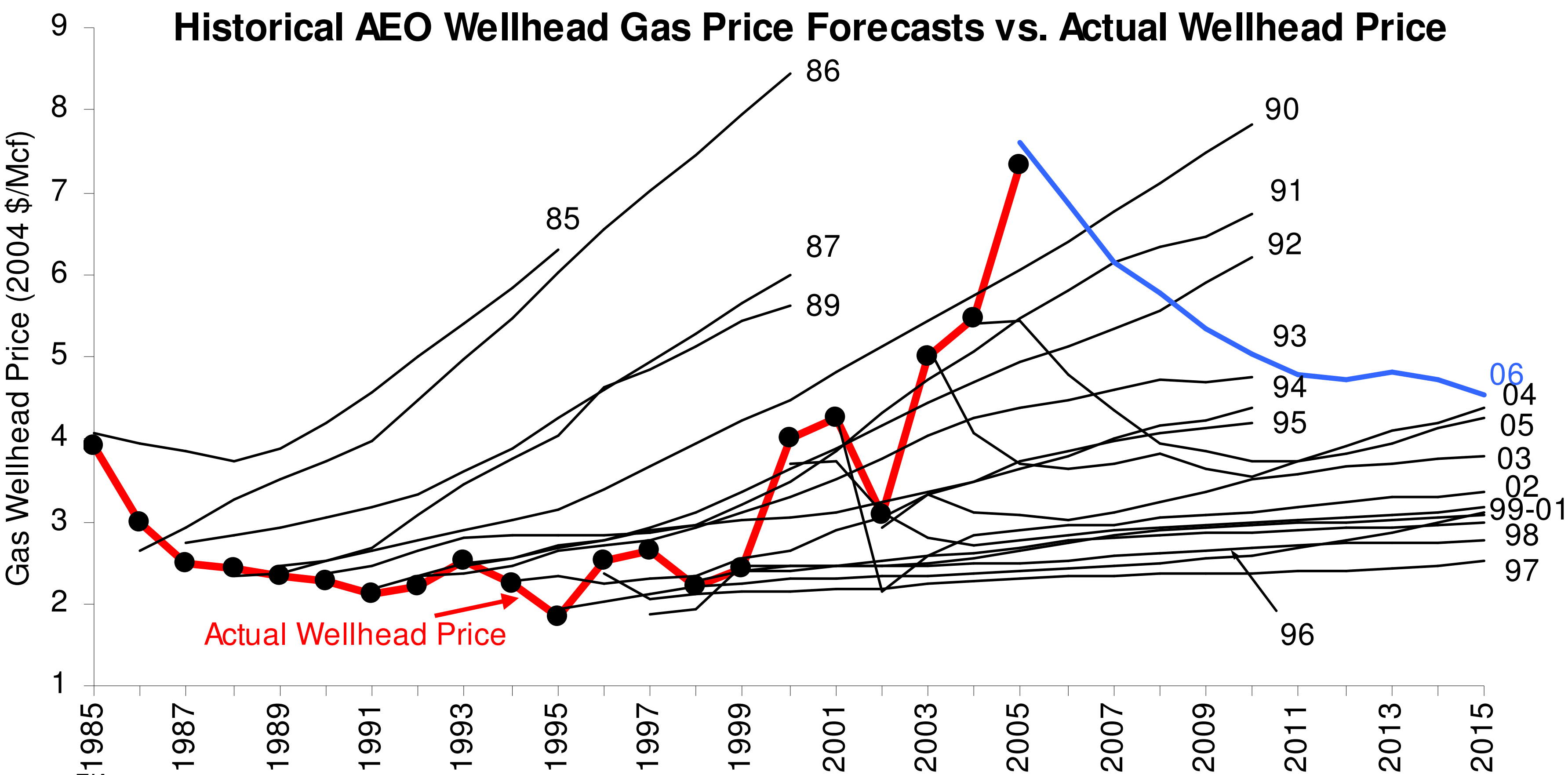
- always maintain full working current version
- background analysis of effects of proposed appliance energy efficiency standards
  - packaged com. AC, utility transformer, residential furnaces & boilers
  - many more upcoming
- develop GPRA cases for the Distribution System Integration Program of the Office of Electricity Distribution and Energy Reliability of DOE
- various other NEMS development work
  - scenarios for use in budget/GPRA preparation (high fuel prices, carbon)
  - power flow layer for NEMS
  - super computer port
- performance analysis
  - transportation model
  - Macroeconomic Activity Module

II. Selected NEMS Results

PRICE FORECAST



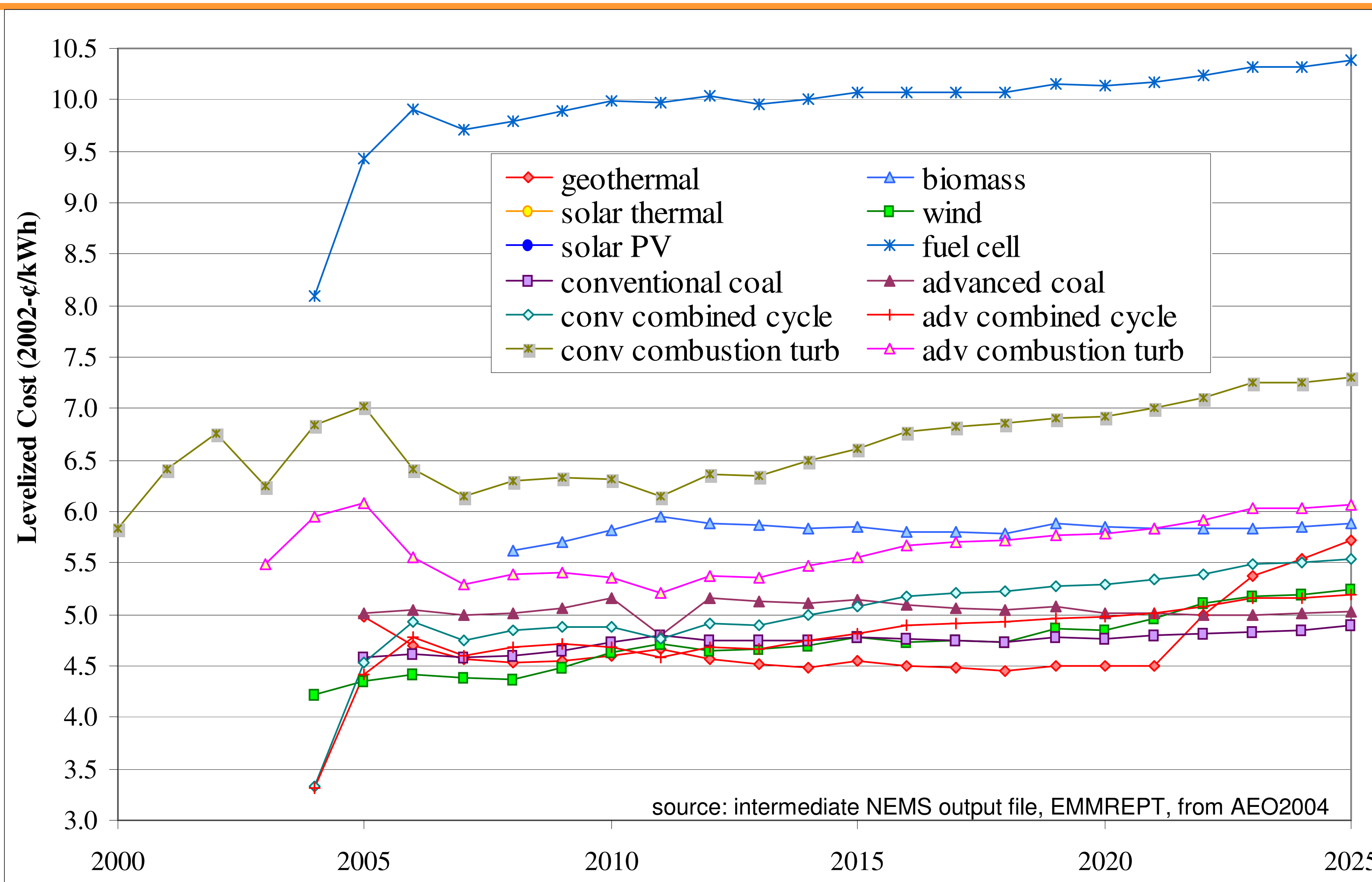
NEMS COMPARISON II



Source: EIA

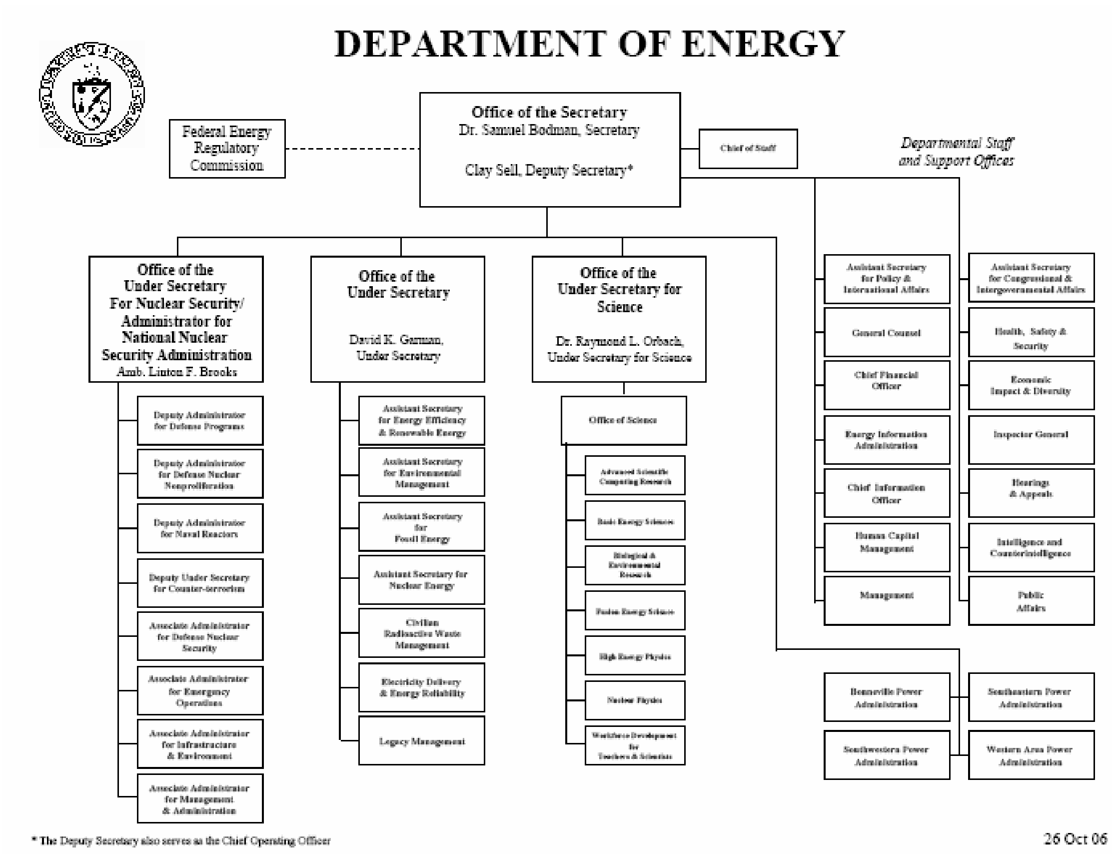
Source: Taken from Figure 9 of "An Overview of Alternative Fossil Price and Carbon Regulation Scenarios", Wiser, R. and M. Bolinger. LBNL-56403. October 2004, with updates courtesy of authors

AEO 2004 Electricity Generation Levelized Cost of Energy



III. Introduction to GPRA

Some Jargon



AEO = Annual Energy Outlook
DE = former Distributed Energy Program of
DER = Distributed Energy Resources of EERE
DOE = U.S. Dept. of Energy
EERE = Office of Energy Efficiency and Renewable Energy
EIA = Energy Information Administration
EMM = Electricity Markets Module of NEMS
FE = Office of Fossil Energy
GPRA = Government Performance and Results Act
NE = Office of Nuclear Energy
NEMS = National Energy Modeling System
PAE = Planning, Analysis and Evaluation

Government Performance and Results Act

- S. 20 GPRA of 1993 requires goals and metrics
- targets accountability and management
- all branches of Federal government set their own goals, own metrics, own methods
- seven current Energy Efficiency and Renewable Energy (EERE) metrics
- programs get credit for *all* the benefits of their activities
- analysis by programs not technologies
- heterogeneous and non-technical targets pose a problem (e.g. 92 GW CHP)
- current analysis is for two budget cycles hence, i.e. we are starting now on GPRA-09

Current EERE GPRA Metrics*

- ENERGY
  - primary non-renewable energy savings (Q/a)
  - generation (TWh/a)
- ECONOMIC
  - energy expenditure savings (B2002$/a)
- ENVIRONMENTAL
  - carbon savings (MtC/a)
- SECURITY
  - oil savings (Mbbl/a)
  - NG savings (Q/a)
  - avoided additions to convent. power plant (GW)
  - program specific capacity added

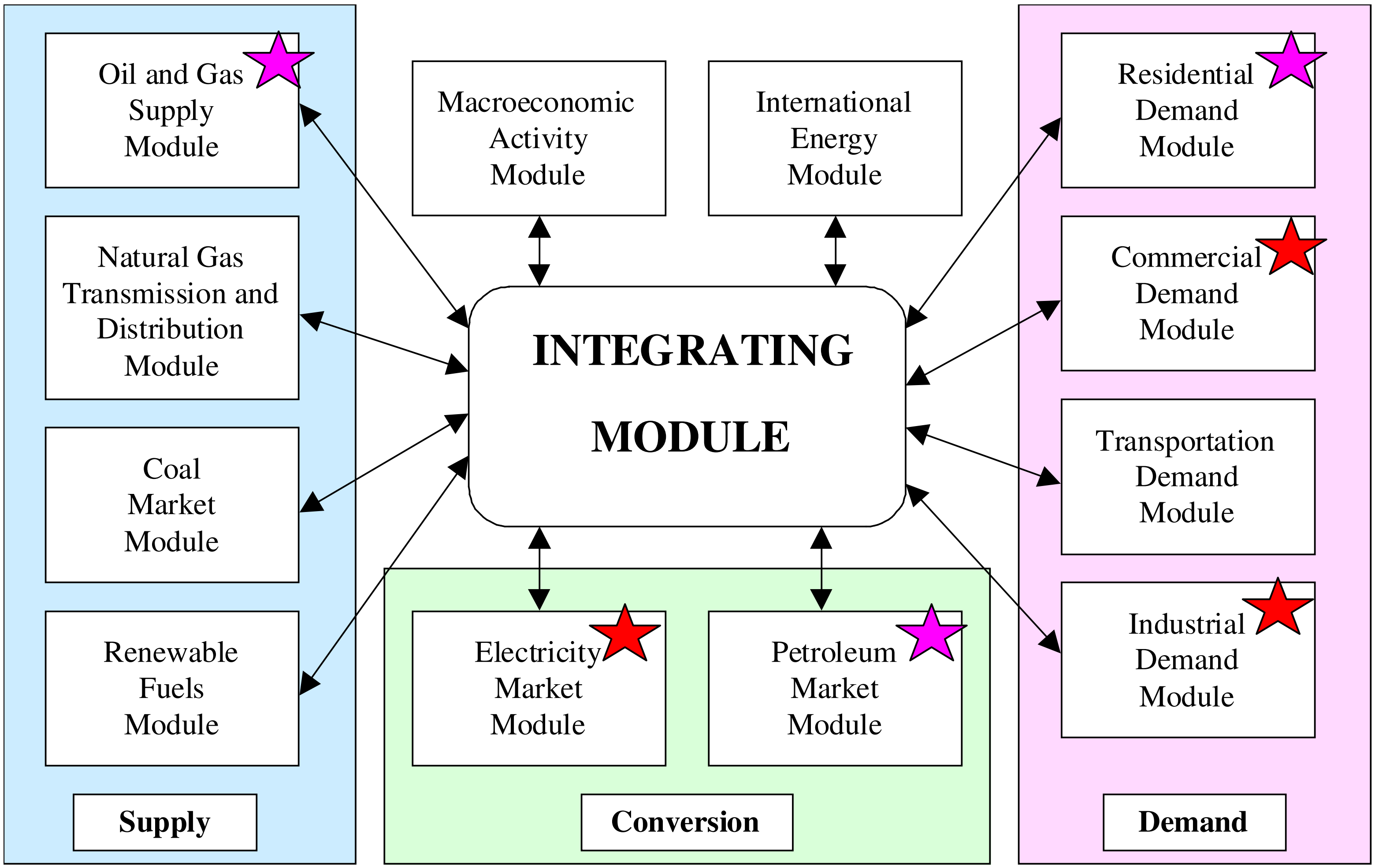
(vary by program)

EERE's Approach to GPRA

- EERE has taken a modeling oriented approach
- this is spreading to other parts of DOE, FE, NE, OE, …
- NEMS is primary tool, MARKAL for longer term
- establishment of PAE is rationalizing process
  - consistency across technology programs
  - Benefits Analysis Team (BAT)
  - NRC Panel results
    - Uncertainty
  - more connection of budget info. 5 year plan, etc.
- consistent "base" and "program" cases
- consistent scenarios, high fuels & carbon constrained

IV. DER in NEMS

The National Energy Modeling System (NEMS)



DER Technologies in NEMS

Available Slots for DE Program Technologies		
Technology Type	Module Name	Representative Size in AEO-4
Gas Turbine	Commercial	1 MW
	Industrial	1 MW, 5 MW, 10 MW …
	Electricity Market (EMM)	2 MW
Microturbine	Commercial	100 kW
Gas Engine	Commercial	200 kW
	Industrial	800 kW, 3 MW
	Electricity Market (EMM)	1 MW
Direct-Fired Chillers	Commercial	N/A

DER Limitations of NEMS

- isolation and inconsistency across sectors/modules
- limited number of technology slots available (non "industrial" microturbines)
- some technologies missing
  - limited size slots
  - all Commercial Module waste heat is valued, but
  - no CHP driven cooling or desiccant dehum., only direct fire
- representation too broad for niche markets
  - regional average tariffs
  - congestion
- limited transmission, reliability, or other benefits, but …
  - EMM transmission credit
  - endogenous treatment of demand displacement
- environmental goals difficult to represent
  - inconsistent or no environmental tracking
- step-function or linear improvements
- AEO incorporates program benefits
  - Tech Characteristics

Mission of the Office of Electricity Delivery and Energy Reliability (OE)

The overall mission of OE is to lead national efforts to modernize the electric grid, enhance the security and reliability of the energy infrastructure, and facilitate recovery from disruptions to the energy supply.

- How would you establish a quantifiable metric that could annually measure progress towards this objective?

OE GPRA Review Coming Up

- facing the review panel in D.C. next month

  Hillard G. Huntington, Stanford University
  Leon Clarke, PNNL
  Joseph F DeCarolis, EPA
  Alexander E Farrell, U.C. Berkeley
  Andy S Kydes, EIA
  Daniel H Loughlin, EPA
  Frederic Murphy, Temple University
  William A Pizer, Resources for the Future
- Where do you start on such a GPRA?

OE Programs for FY08?

program	*budget*
Distribution System Integration *(includes microgrids)*	~ 30 M$
High Temp. Superconductivity	~ 50 M$
Energy Storage & Power Electronics	~ 50 M$
Visualization & Controls	~ 20 M$

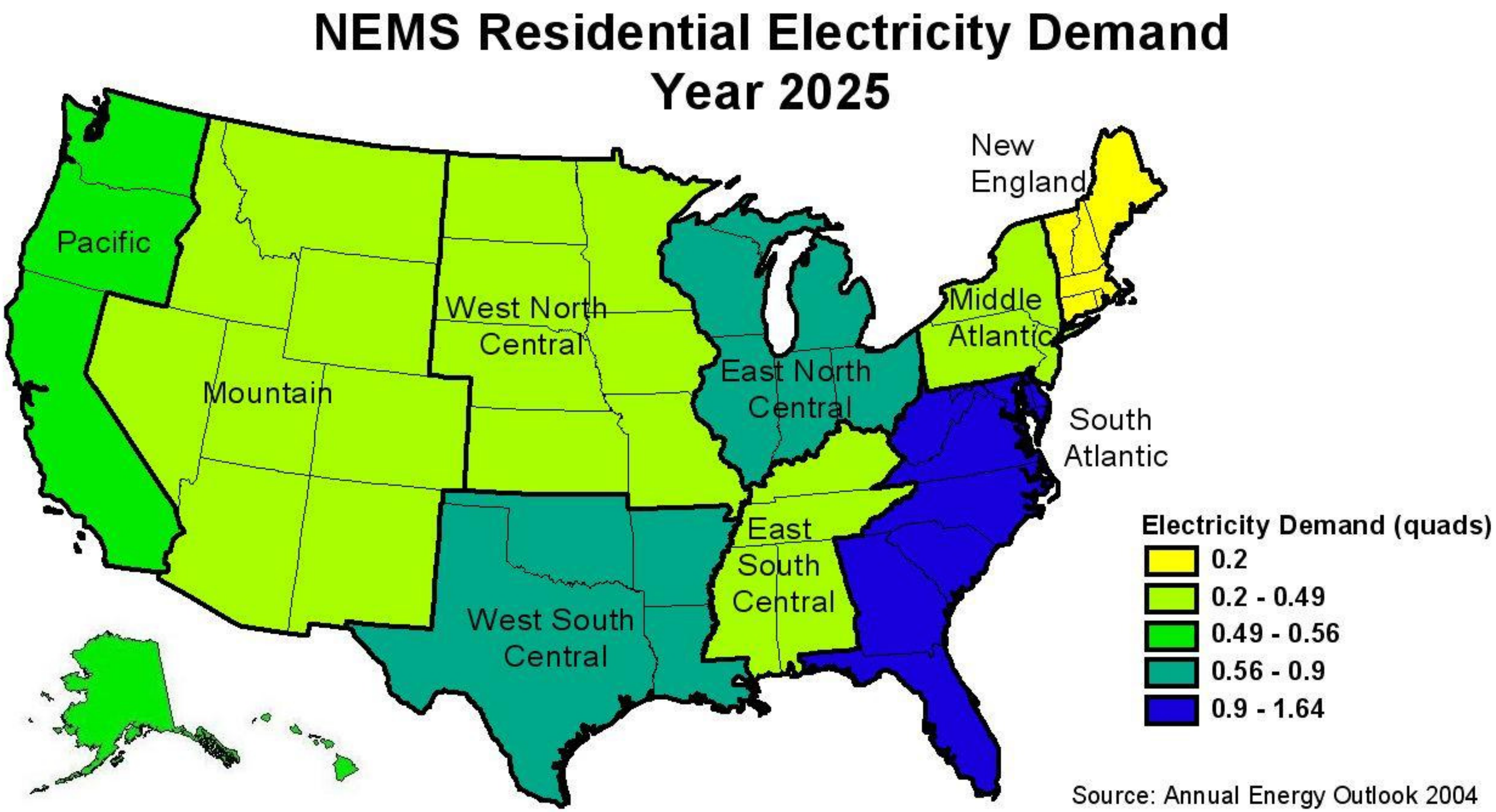
FY06	95 M$
FY07 request	125 M$
FY07 Senate mark	178 M$
FY07 House mark	100 M$
net FY06 earmark loss	28 %

V. Residential Electricity Demand Forecast Disaggregation

Disaggregation of NEMS Demand Forecasts

- Goal of project is to take NEMS national forecasts of energy demand and disaggregate them to the county level.
- Relies population growth forecasts by county and climate.
- Provides a NEMS compatible way to forecast EERE technology adoption at the county level.

Geographic Scale of the Demand Side in NEMS



Disaggregated by Population and Climate

NEMS Energy Forecasts (census division, year, sector, fuel)

↓

Distribute by Population (county, year)

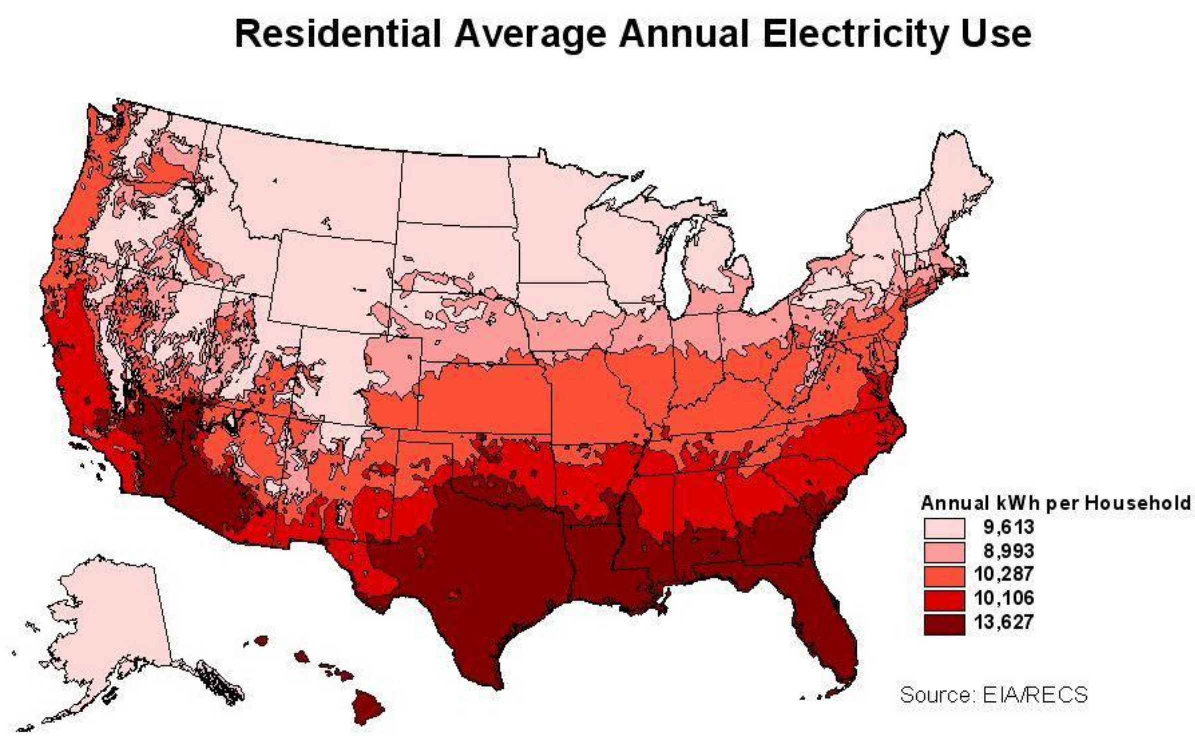
↓

Distribute by Climate (climate zone, sector)

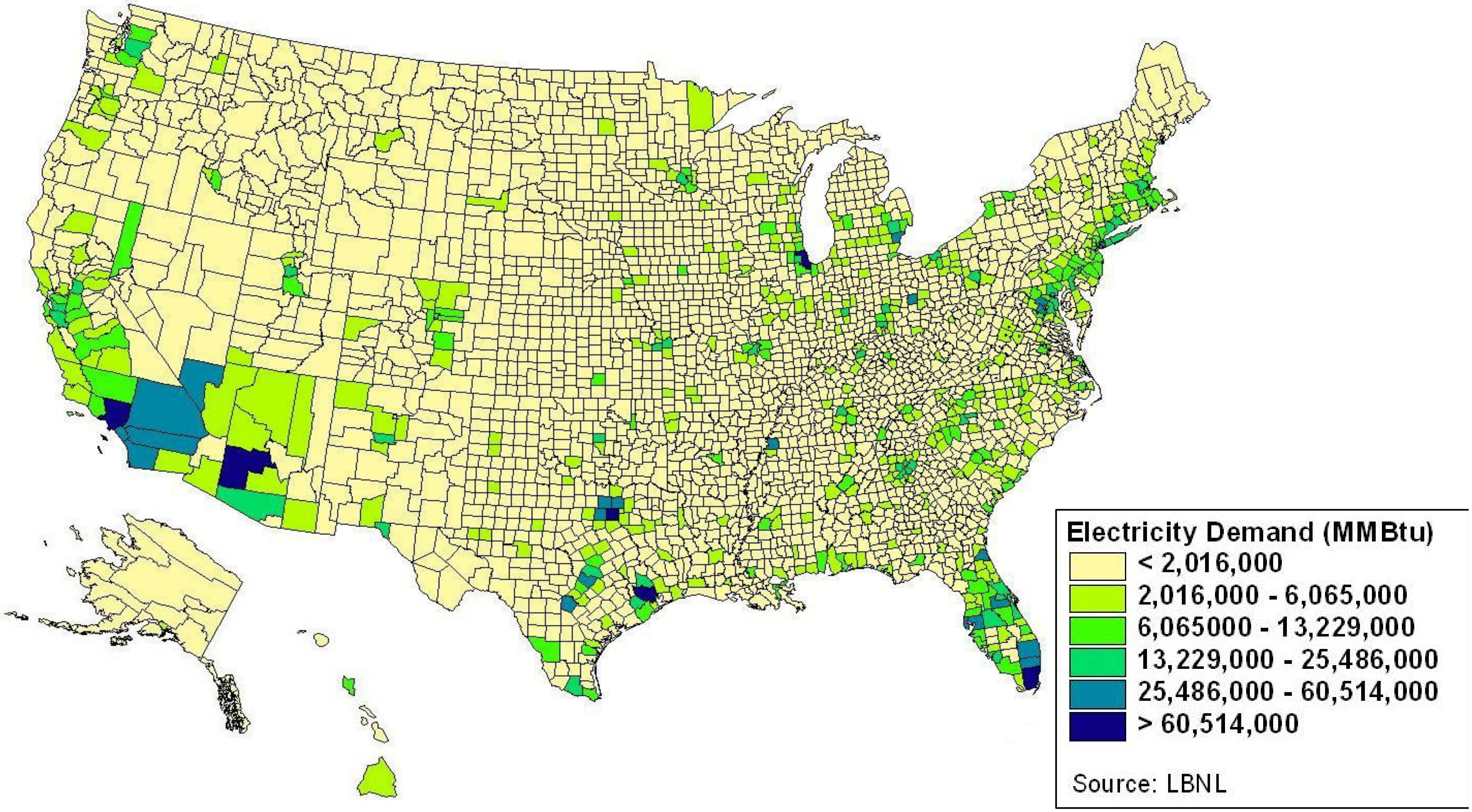
↓

Normalize by NEMS Energy Totals (census division, year, sector, fuel)

- Population forecasts by county
  (www.epa.gov/ttn/naaqs/ozone/areas/pop/pop_proj.htm)
- Climatic effects on annual energy intensities
  (1999 CBECS and 2001 RECS)

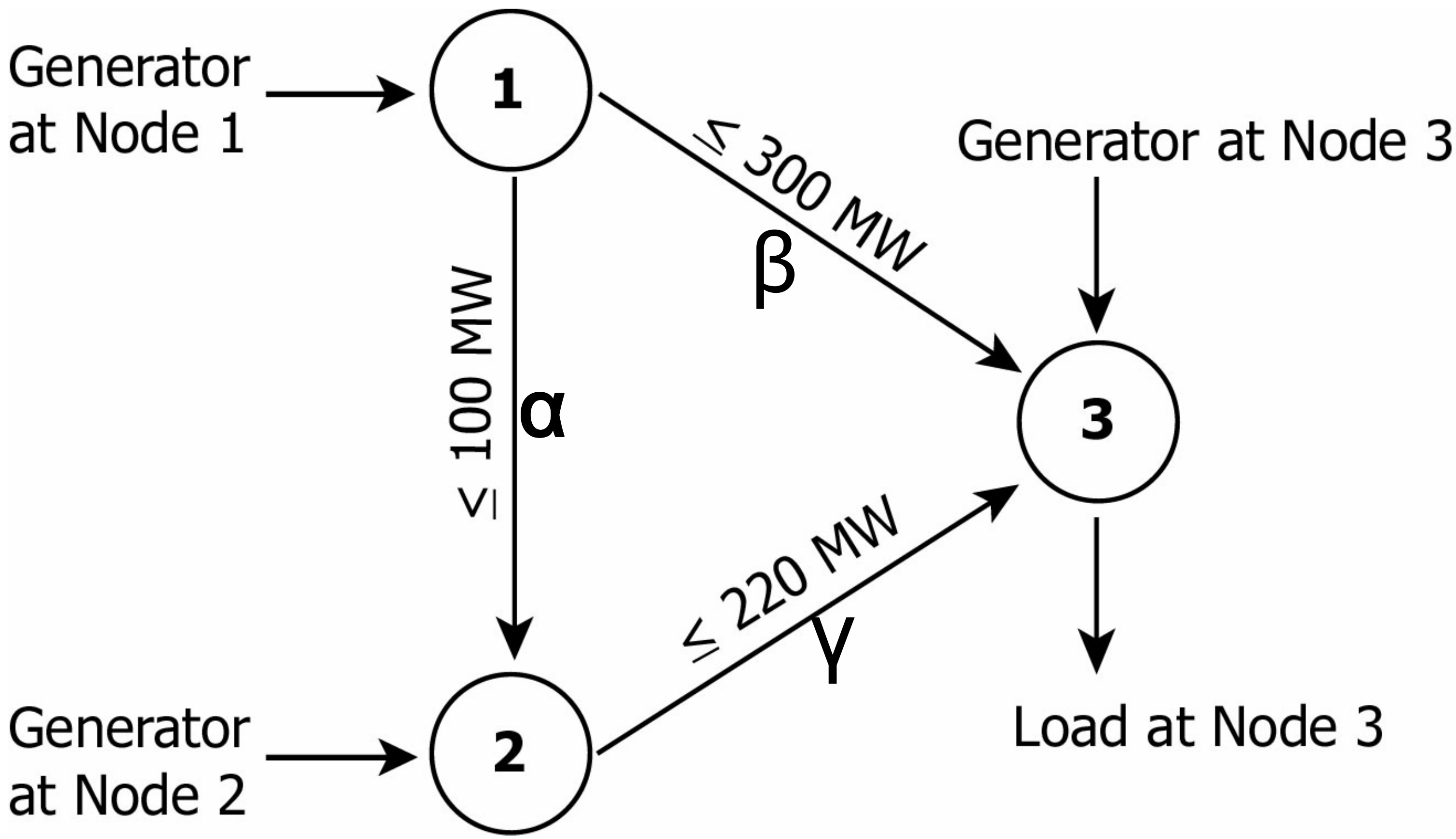


Output- Total Residential Electricity Use in 2025 by County

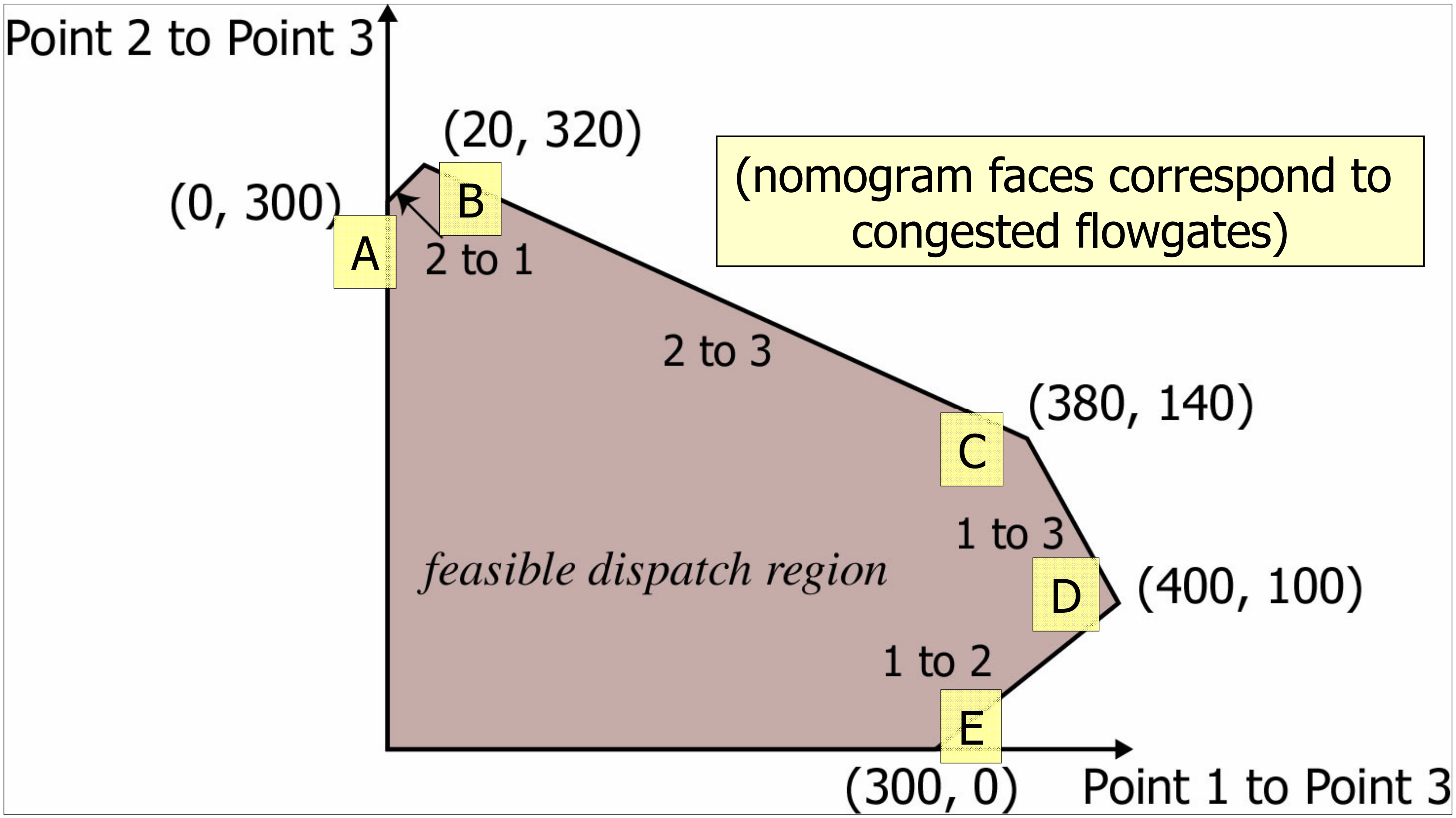


VI. Developing an EMM Power Flow Layer

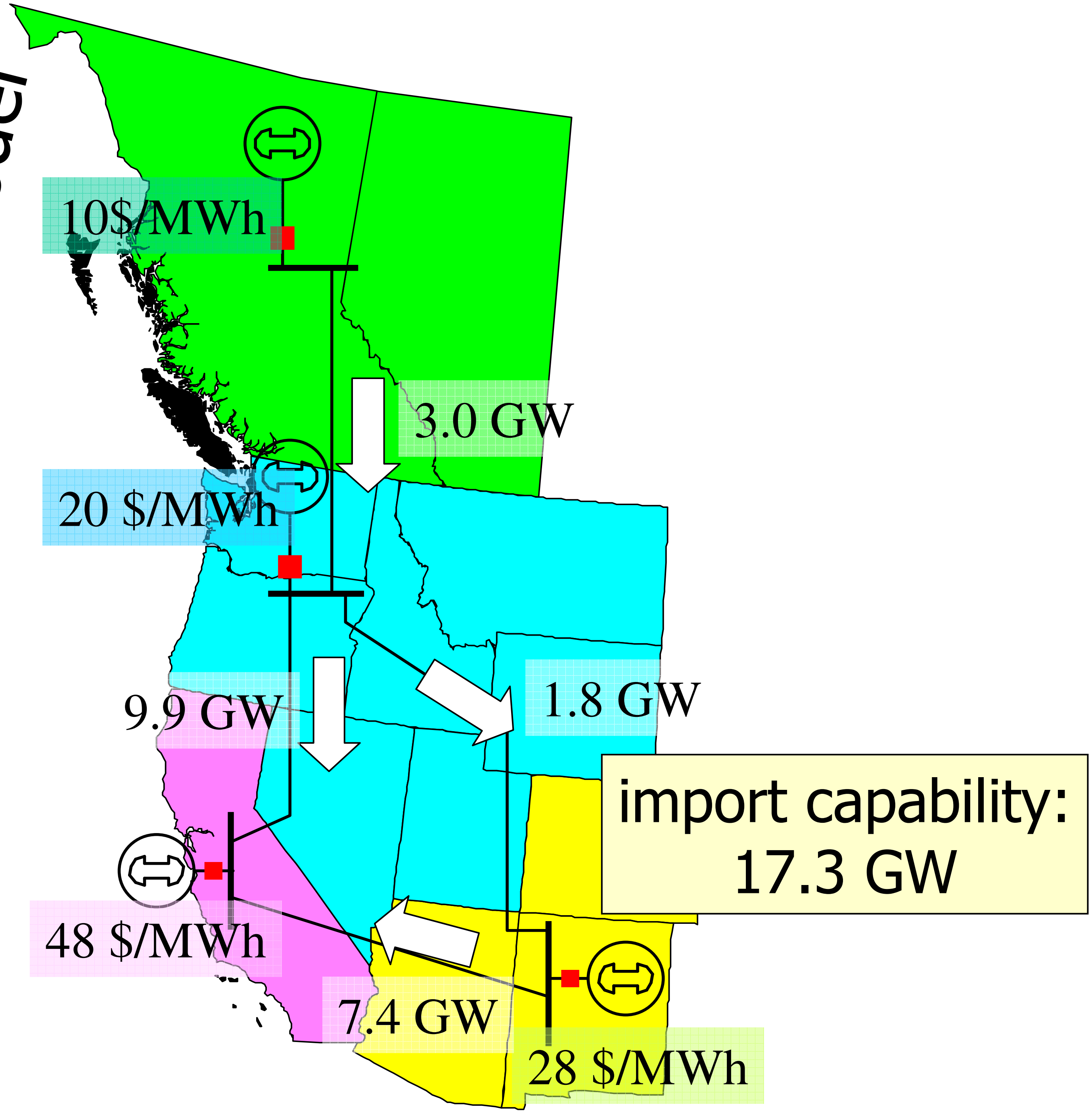
Three-Node DC Example



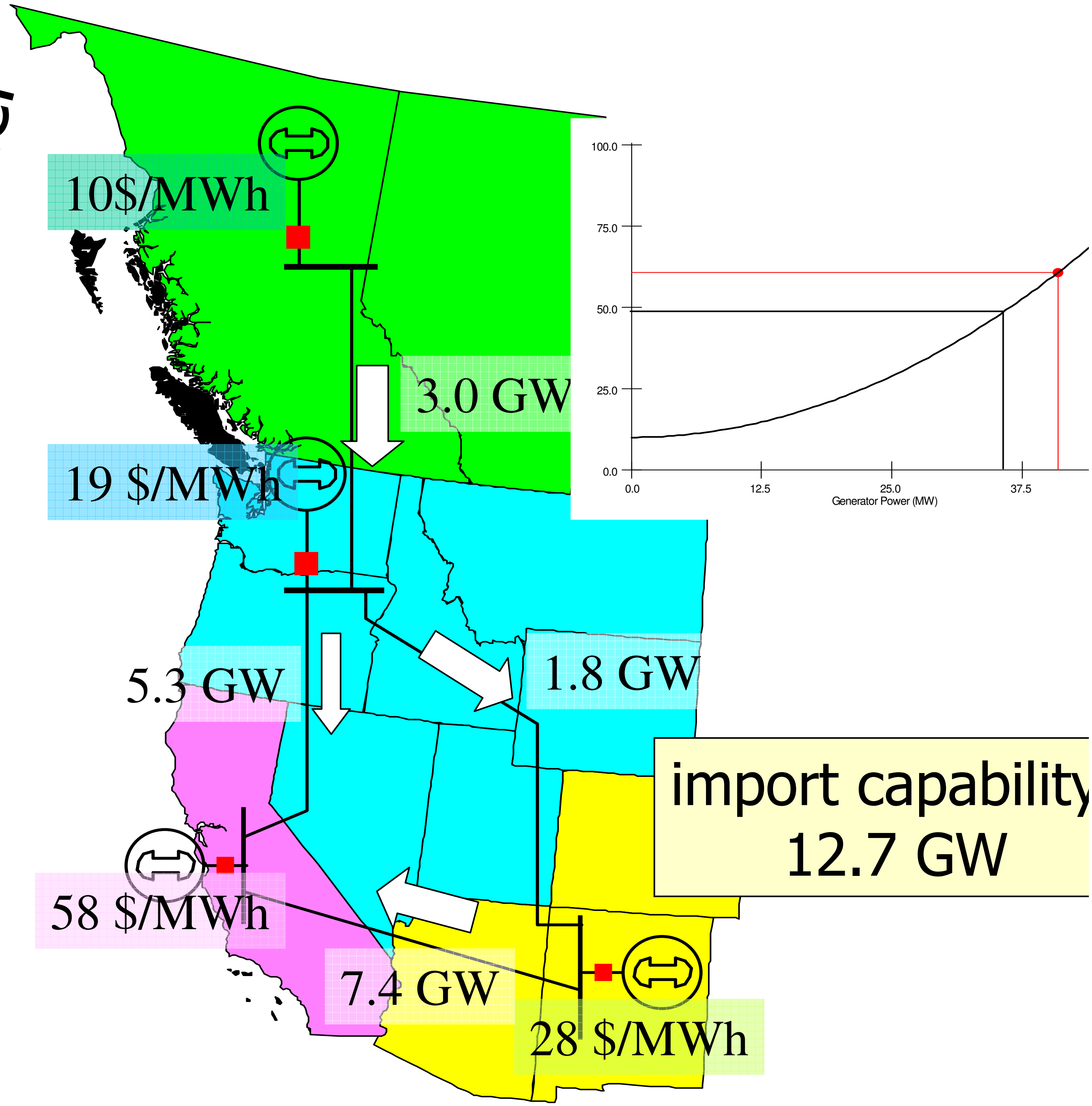
Nomogram Shows Actual Flow Limits



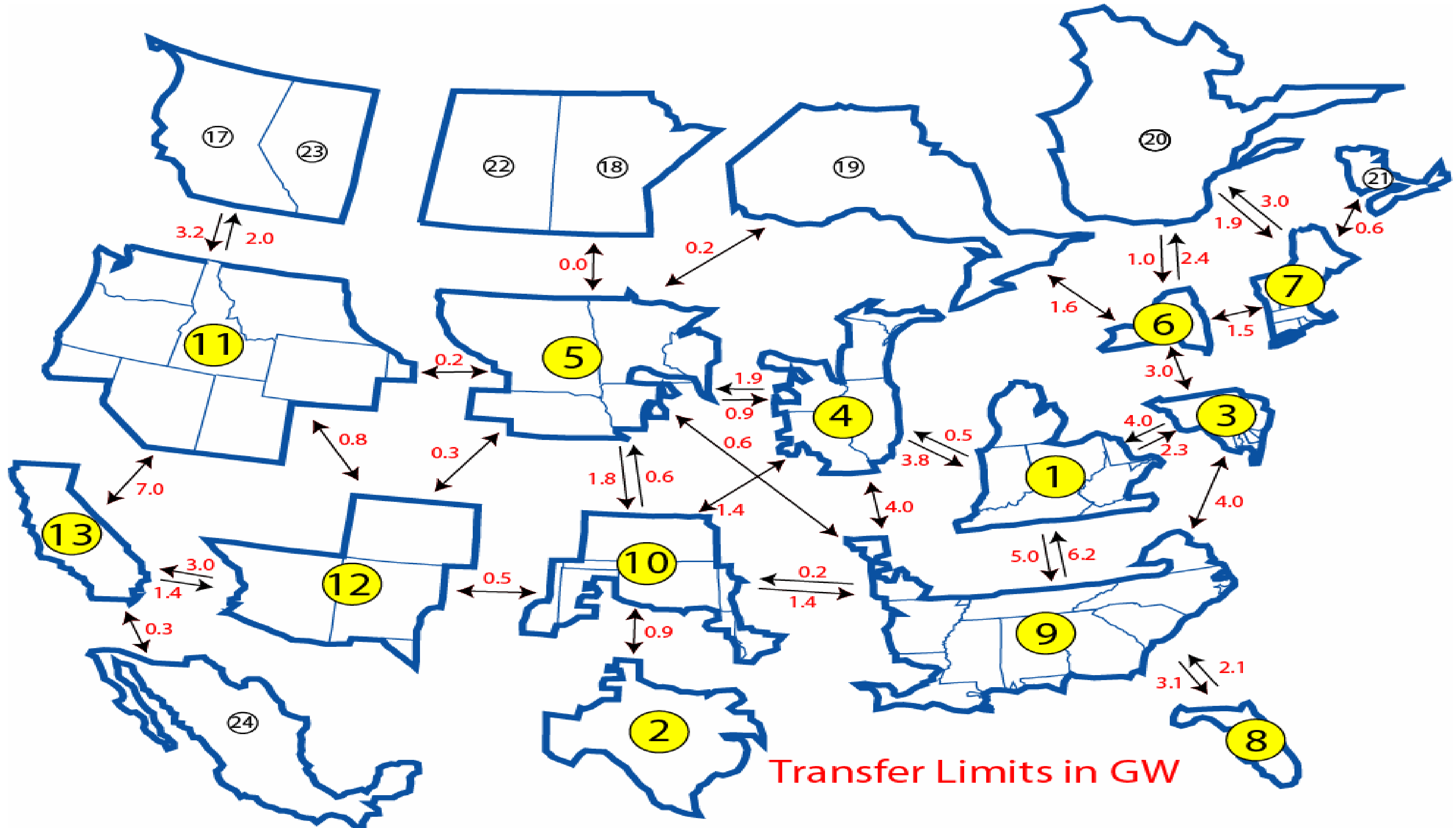
California Imports Under a Transportation Model



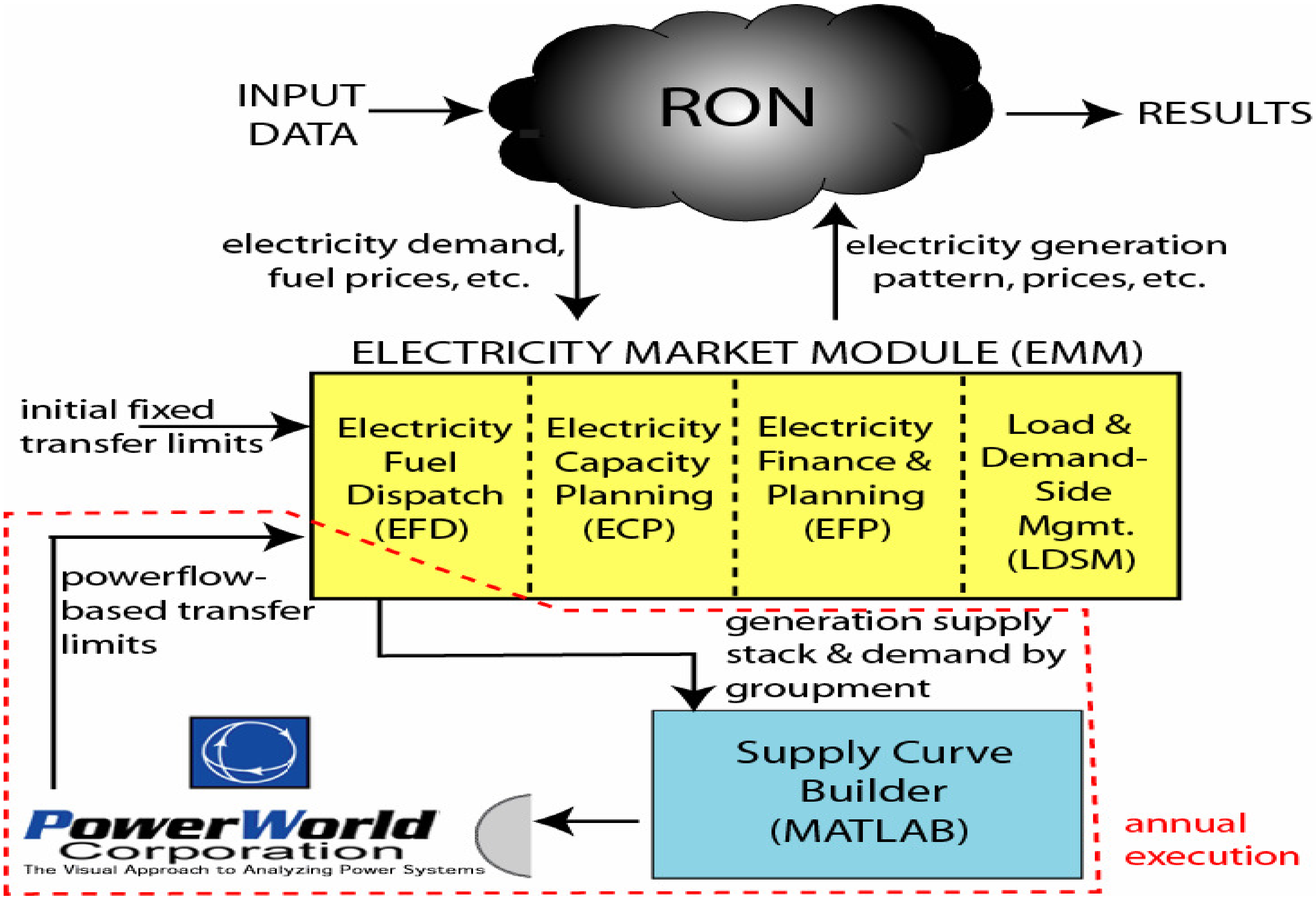
California Imports Under a DC Power Flow Model



Transportation Model Transfer Limits in NEMS

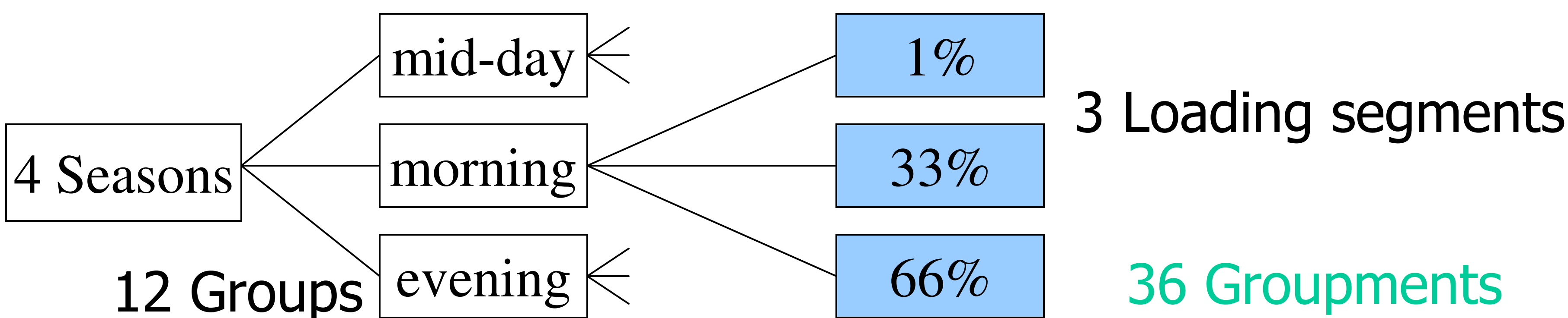


Data Flow for Power Flow



Power Flow Model

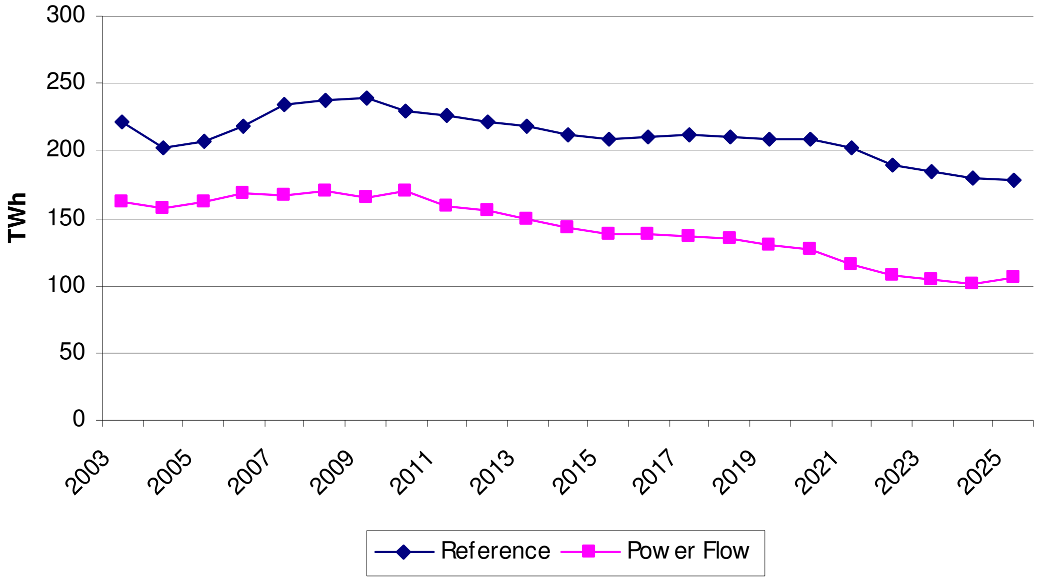
- equivalencing: produced relative impedances between areas by reducing a detailed model of more than 45,000 nodes and 60,000 lines down to the NEMS resolution of 21 nodes and fewer than 60 lines.
- expanded NEMS capability to allow specification of transmission capabilities for each "groupment."



Power Flow – NEMS Model

- demand and supply stack extracted from NEMS for each *groupment*.
  - includes all generators in the NEMS model, "must-runs" and approximately 4500 for economic dispatch. Compiled for each groupment (36) for each year (30).
- iterate between PowerWorld and NEMS, adjusting the NEMS limits to the value of the power flow results

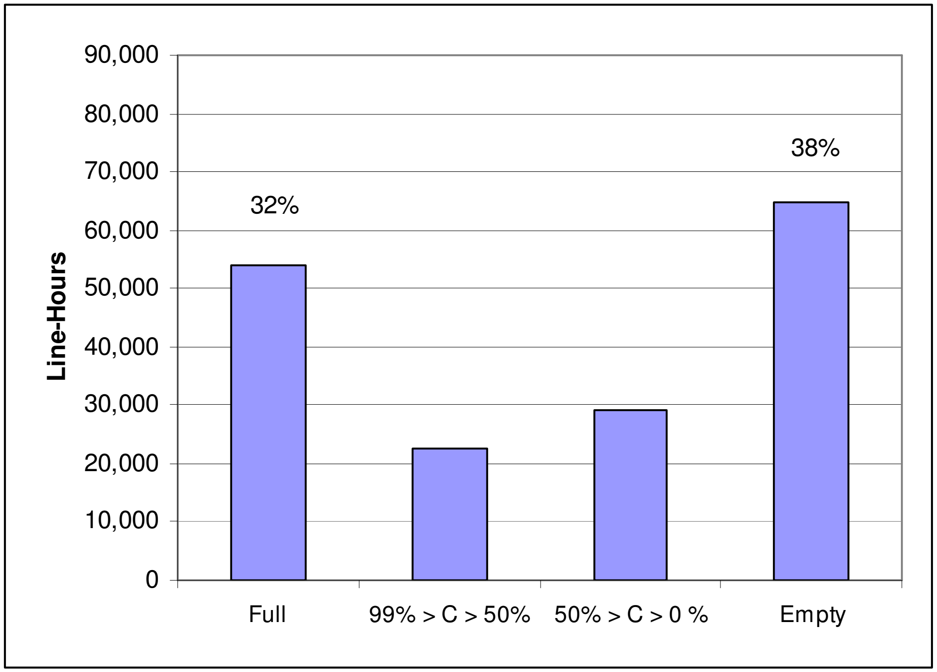
Result: Transmission Usage



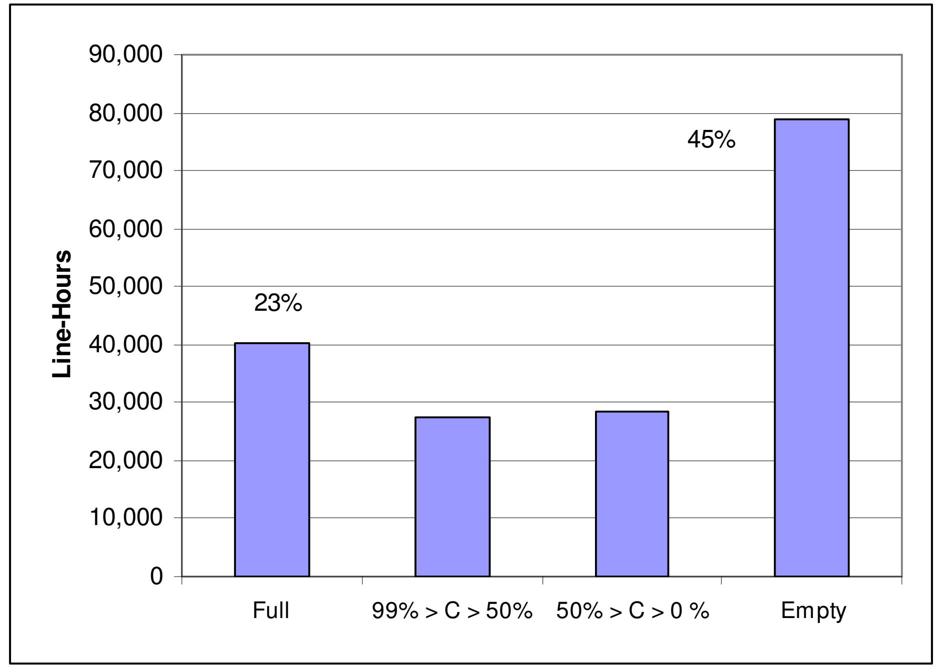
As expected, with the power flow limits the transmission usage decreases significantly.

Surprisingly, the transmission usage tends to decrease over time in both the reference and power flow cases. Investigate further…

Result: Transmission Congestion



2015



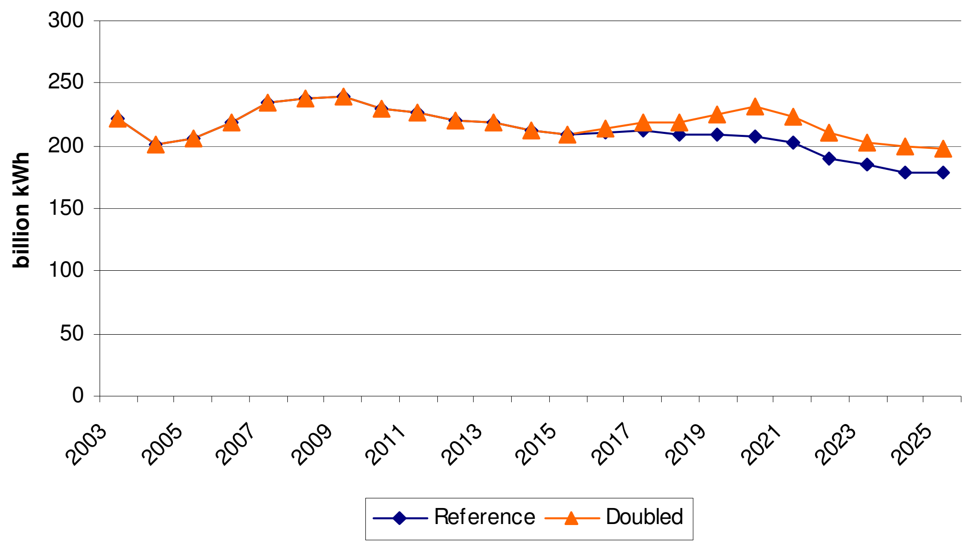
2025

transmission congestion decreases with time.

investigate further…

Result: Double Capacity

test the effect of doubling the transmission capacity

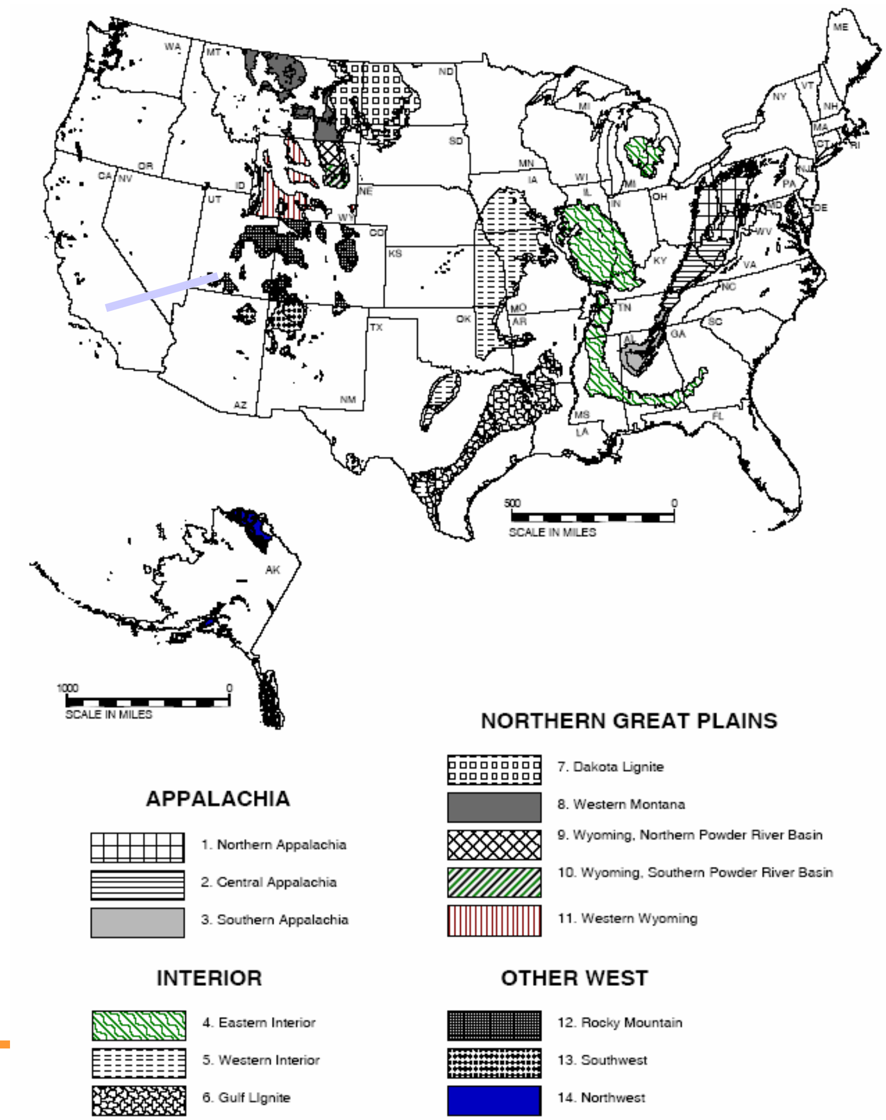


Doubling the capacity does not dramatically increase transmission usage!

ECP Module: Build Logic

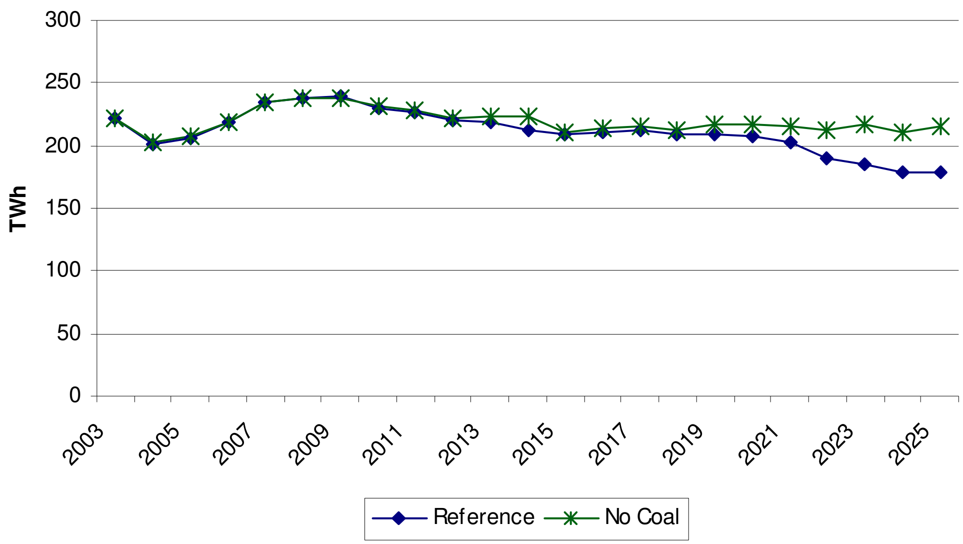
- NEMS automatically places new generation capacity "close" to load.
- economic, "out of region" builds not allowed, except …
- some new coal and natural gas plants built in one region may be attributed to another, without explicit transmission links.

Coal Regions



Technologies Division

Result: No Coal Scenario

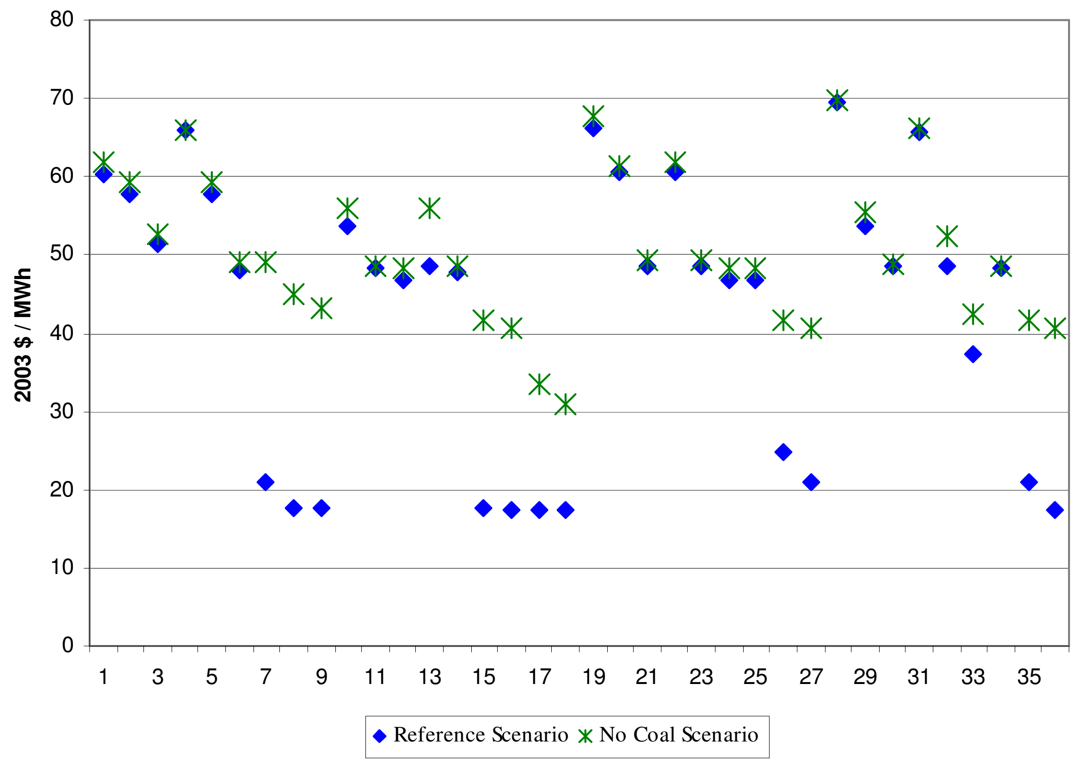


no Coal Scenario slightly increases transmission usage overall

in 2025, California imported 24 TWh more energy in the no coal scenario

In GWh	Reference	No Coal	Total Increase
From Region 11	33,864	47,397	13,533
From Region 12	0	10,751	10,751
Net	-	-	**24,284**

Result: No Coal Scenario



2025 Electricity Prices in California

peak prices remain the same

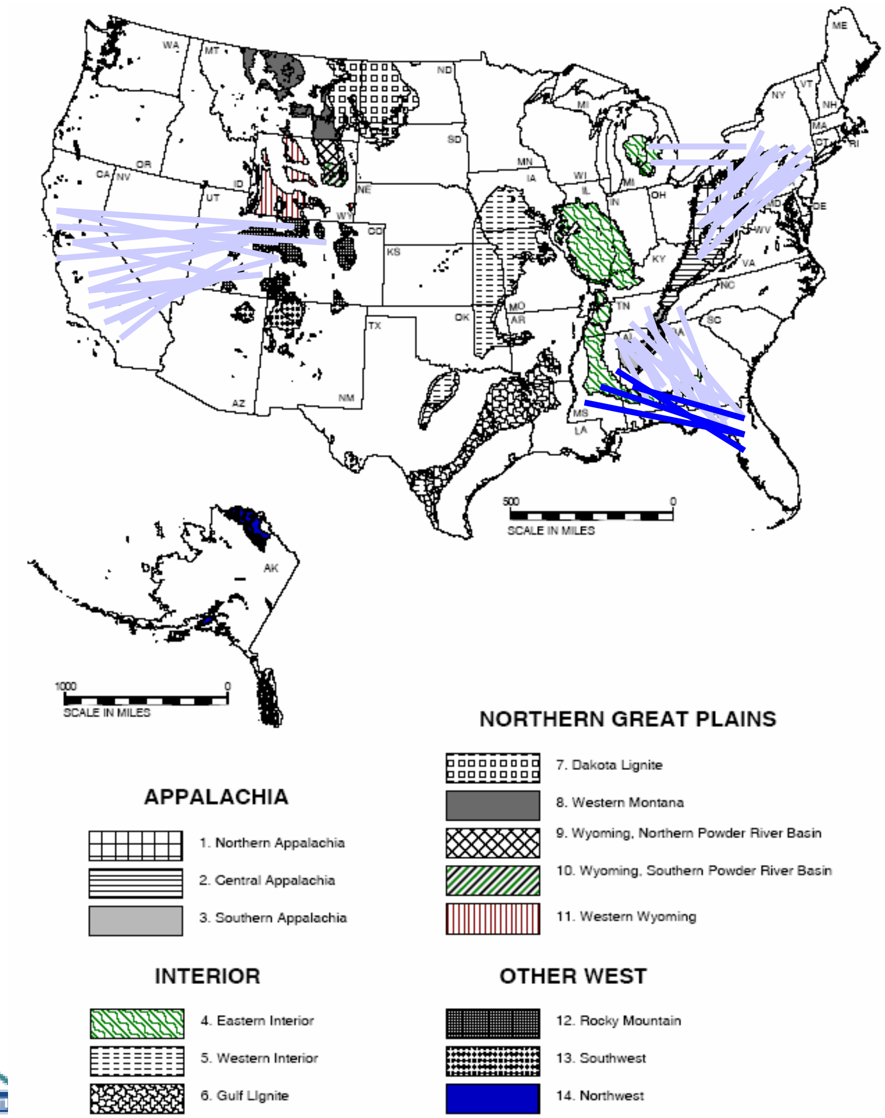
without the coal plants, prices increase during base-load periods

The Invisible Grid

Additional generation capacity without transmission (modeled)

Demand Region	Number of New Plants	Generating Capacity	Type of Plant and Locations
NY (6)	15	7.2 GW	Coal built in ECAR (1) or MAAC (3)
FL (8)	14	15.7 GW	Coal built in SERC (9)
California (13)	17	14.9 GW	Coal built in NPP (11) and Rocky Mt (12)
FL (8)	4	7.9 GW	Combined Cycle built in SERC (9)
Total	**50**	**45.7 GW**	

The Invisible Grid



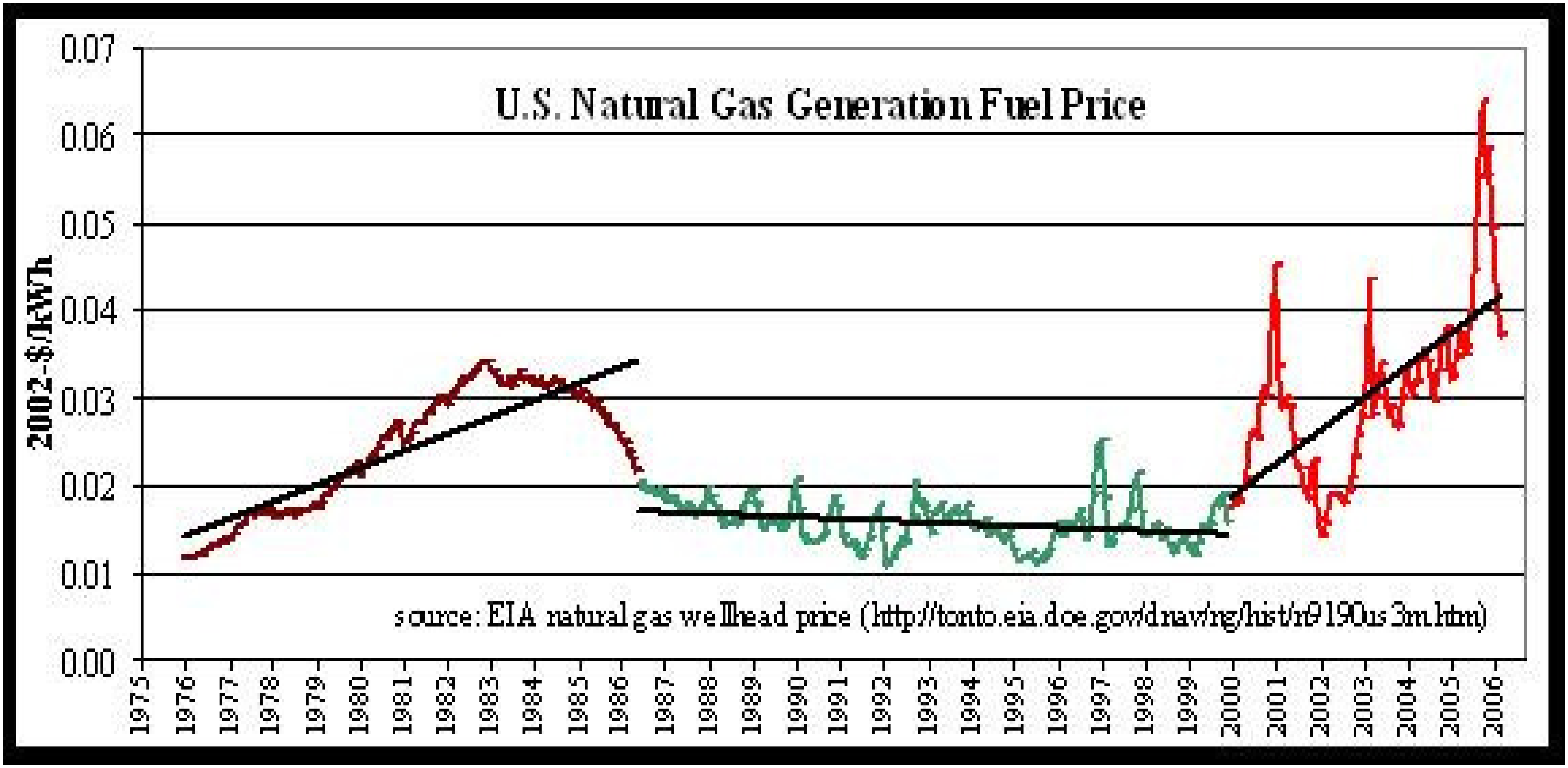
- true location of new plants and their dedicated (invisible) transmission are not known
- only their regions
- physical grid becomes obsolete

Results of Power Flow Exercise

- over time transmission becomes obsolete because plant is built where load grows
- inconsistency of NEMS regions means that coal plant built for high cost states, e.g. CA, is treated as if it's in that state
- as long as new plant economics justify dedicated transmission, it's built
- the way transmission is modeled becomes moot over time
- this pattern is invisible to users

VII. Uncertainty in NEMS

U.S. Natural Gas Generation Fuel Price



Source: EIA natural gas wellhead price (http://tonto.eia.doe.gov/dnav/ng/hist/n9190us3m.htm)

Scenarios to Represent Uncertainty

- worked with NETL & FE staff to develop common scenarios, reviewed scenarios developed by EIA

  Berkeley Lab report ("Scenarios for Benefits Analysis …")

  Aug. 2005 (http://eetd.lbl.gov/ea/ems/reports/58009.pdf)
- developed a simple model of options value

  Berkeley Lab report ("Real Options Valuation…")

  Mar. 2005 (http://eetd.lbl.gov/ea/ems/reports/58000.pdf)
- sensitivity analysis is varying one parameter at a time, scenario analysis is varying several, especially to represent one anxiety causing state of the world

EE-FE High Fuel Price Scenario

High Fuel Price Scenario

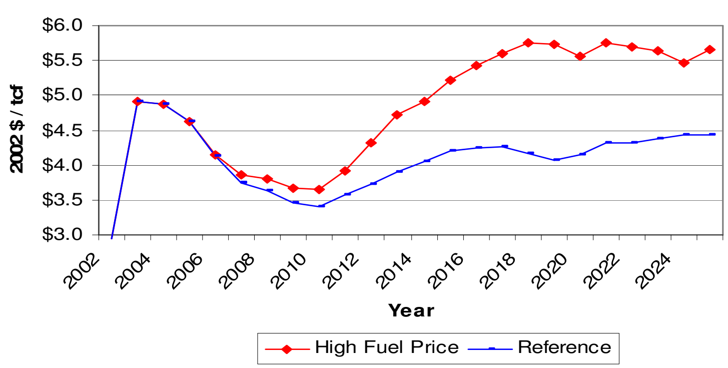
Involved changing exogenous inputs to LBNL-NEMS for oil price forecast.

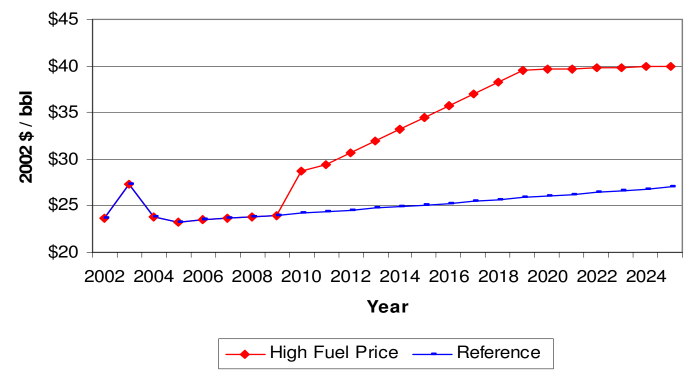
For Natural Gas forecast, three restrictions achieved the price path.

A) No new LNG plants and existing LNG plants could not expand as much as do in Reference Scenario.

B) Canadian NG supply was reduced.

C) Alaska pipeline was delayed beyond 2025.

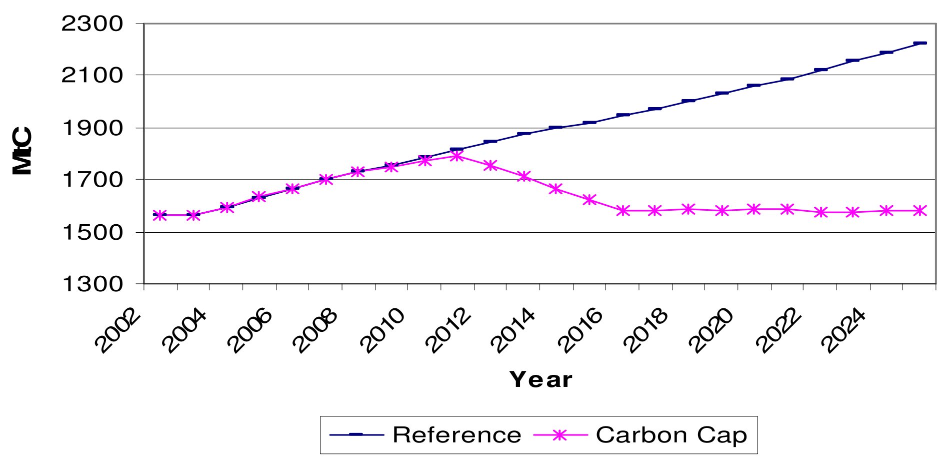




Carbon Constrained Scenario

Carbon Cap Scenario

This scenario is just like Reference Scenario with a cap and trade carbon constraint added starting in 2011.

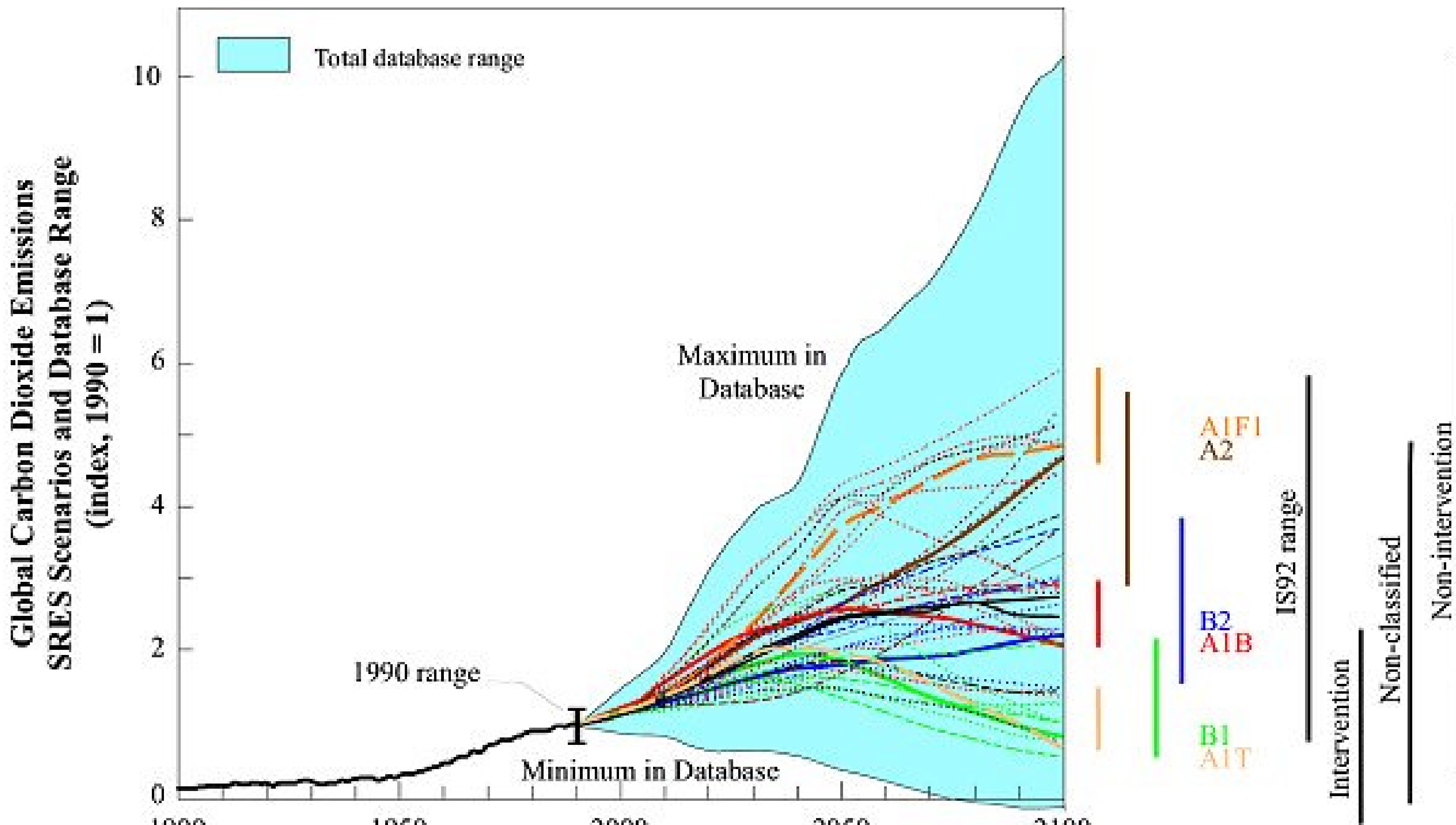


VIII. Stochastic Energy Deployment System

SEDS

- Stochastic Energy Deployment Systems developed by NREL
- Effects of uncertainty are not reflected in a point estimate.
- Need a macroscopic model that
  - captures major drivers of uncertainty
  - allows several inputs to be varied simultaneously
  - presents output that is easy to understand and base policy upon

Forecast Uncertainty



Design of SEDS

- Generates forecast 50 yrs into the future.
- Takes distribution of several uncertain variables as input (such as price of electricity, price elasticity, climate change, etc.)
- Performs Monte Carlo simulation
- Presents summary statistics
- Model built in Analytica

Sample Output (1)

SEDS AEO 2005 Base -- Analytica® Trial -- C:\Research\lbl\SEDS\Model\SEDS_AE - [Result - Generation by tech type]

File Edit Object Definition Result Diagram Window Help

Mean Value of Generation by tech type (GWh / yr)

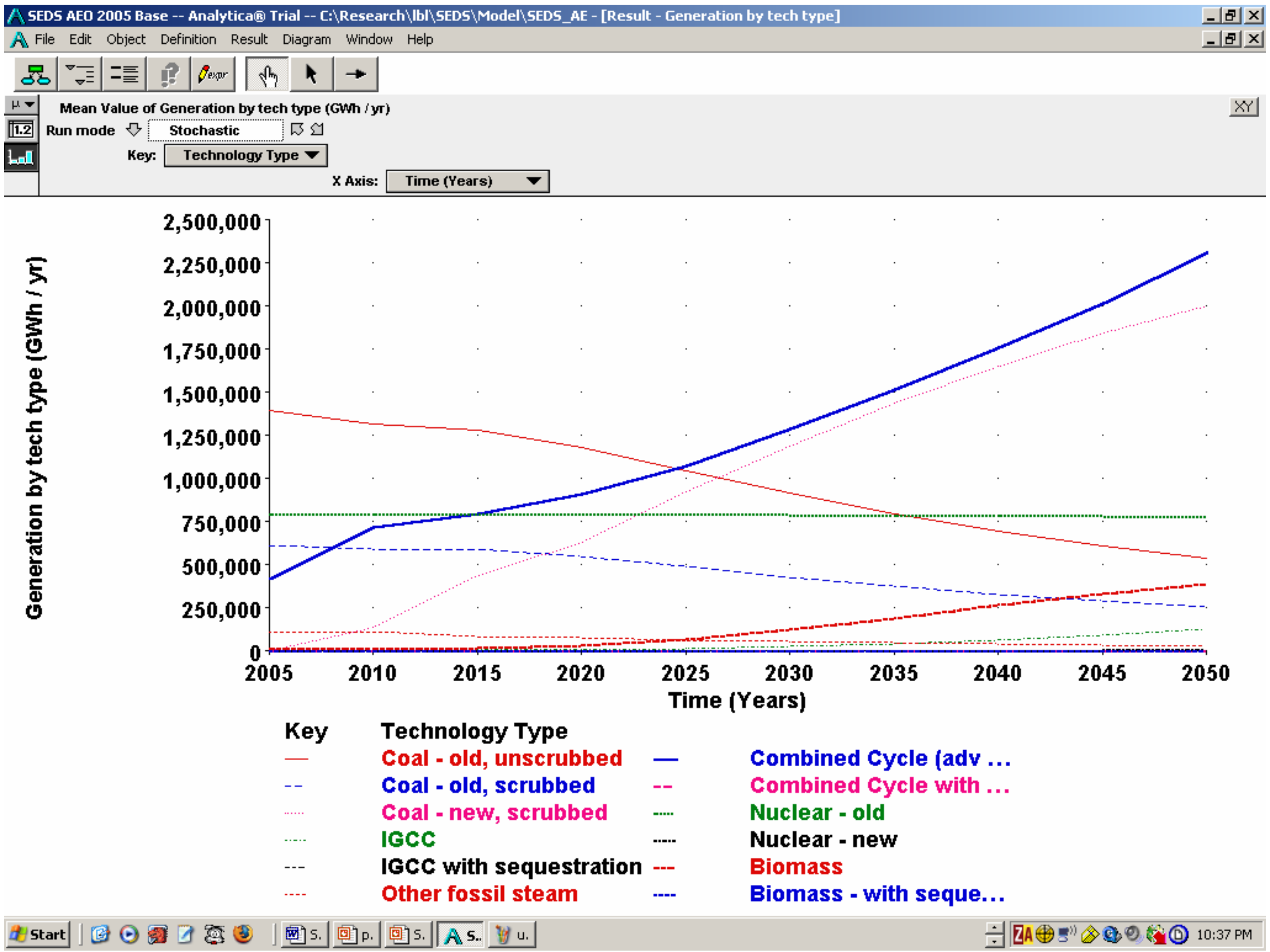
Run mode: Stochastic

Technology Type ☑ Totals

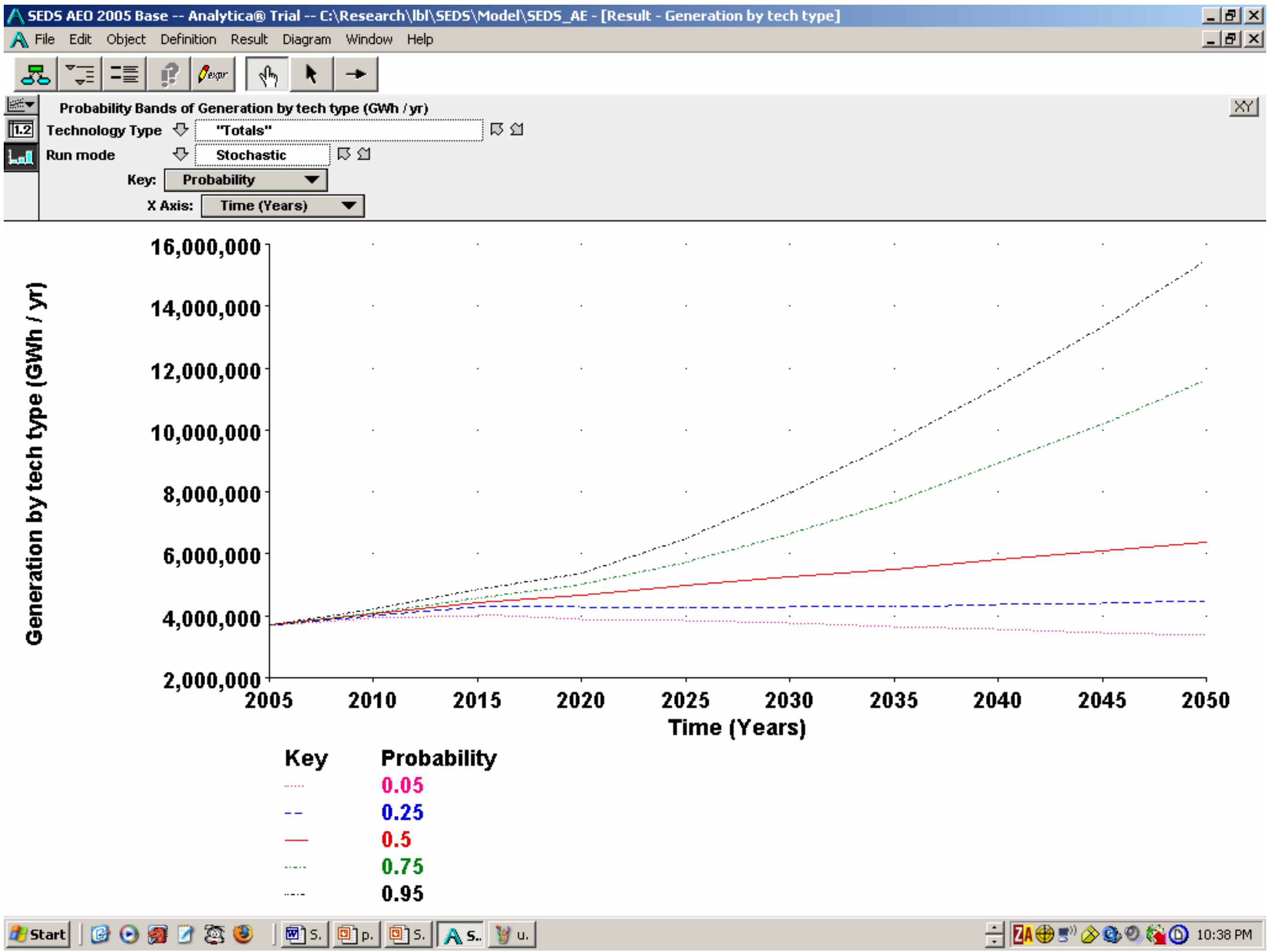
Time (Years) ☐ Totals

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Coal - old, unscrubbed	1,392,998	1,314,245	1,276,314	1,181,158	1,043,430	912,027	795,751	695,520	608,694	533,264
Coal - old, scrubbed	607,002	584,406	584,406	543,229	482,175	421,991	368,633	322,395	282,303	247,449
Coal - new, scrubbed	0	136,171	437,019	625,365	923,545	1,188,904	1,436,558	1,649,787	1,842,231	2,002,272
IGCC	0	2,177	5,360	8,821	16,855	28,616	45,073	65,939	93,040	127,776
IGCC with sequestration	0	0	3	11	61	177	401	777	1,396	2,364
Other fossil steam	108,000	109,745	78,704	72,784	60,220	49,704	41,424	34,559	28,620	23,111
Combined Cycle (adv gas/oil)	419,293	723,409	801,249	913,905	1,081,507	1,294,778	1,523,227	1,766,175	2,022,975	2,313,326
Combined Cycle with sequestration	0	0	2	10	56	173	427	919	1,859	3,606
Nuclear - old	796,300	790,323	790,323	790,323	790,283	789,244	787,327	784,546	780,878	776,527
Nuclear - new	0	0	7	25	143	485	1,298	2,894	5,884	11,126
Biomass	13,040	13,727	21,673	32,728	68,941	125,031	194,735	268,243	336,852	395,697
Biomass - with sequestration	0	0	3	12	74	216	476	873	1,384	1,959
Geothermal (existing)	16,874	21,190	24,083	26,634	31,346	35,884	39,286	41,361	42,586	43,324
Geothermal (EGS)	0	827	2,107	3,679	8,351	15,772	25,730	37,690	52,178	69,379
Wind	22,859	41,126	61,135	86,134	153,235	258,853	399,999	567,368	764,072	992,182
CSP	1,148	1,660	1,983	2,281	2,910	3,689	4,539	5,394	6,273	7,179
PV	141	200	230	253	299	353	409	463	515	568
Hydro	285,000	290,736	290,736	290,736	290,736	290,736	290,736	290,736	290,736	290,736
Combustion Turbines	30,707	18,565	35,328	46,531	59,145	72,403	85,686	99,434	113,469	128,077
MSW-Landfill Gas	21,757	22,904	22,904	22,904	22,904	22,904	22,904	22,904	22,904	22,904
Totals	3,715,120	4,071,412	4,433,566	4,647,522	5,036,214	5,511,939	6,064,620	6,657,976	7,298,848	7,992,825

Sample Output (2)



Sample Output (3)



Berkeley Lab Contribution

- SEDS demand module
- Objectives
  - flexibility (provide user switches to turn on desired model features)
  - speed
  - validity of forecast formulae over large time horizons

High Level Design

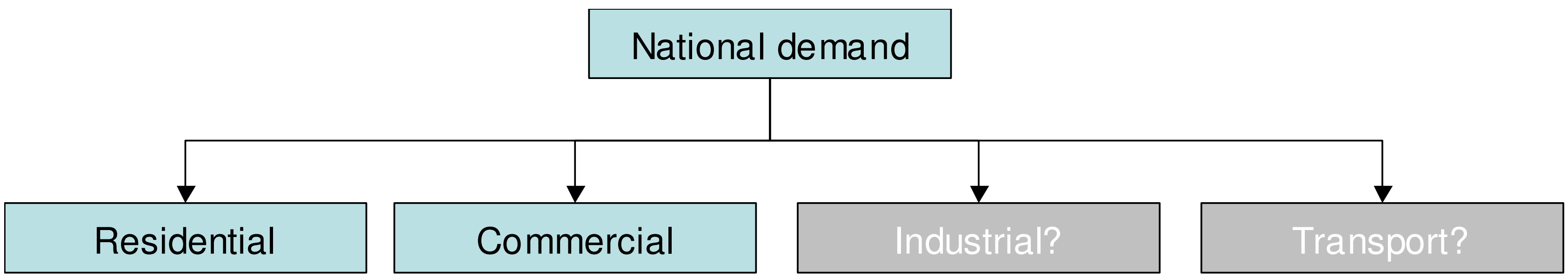
- Forecast generated at varying levels of detail
- Higher levels based on econometric models
- Lower level based on physical models
- Give user control to pick level of detail

Level 1 Forecast

- National level demand generated based on linear regression of price elasticity, market inertia, climate, GDP, population, income, floor-space
- Market inertia, climate, etc. modeled as uncertain variables sampled from distribution
- Econometric models may be invalid outside the range of fitted data

Level 2 Forecast

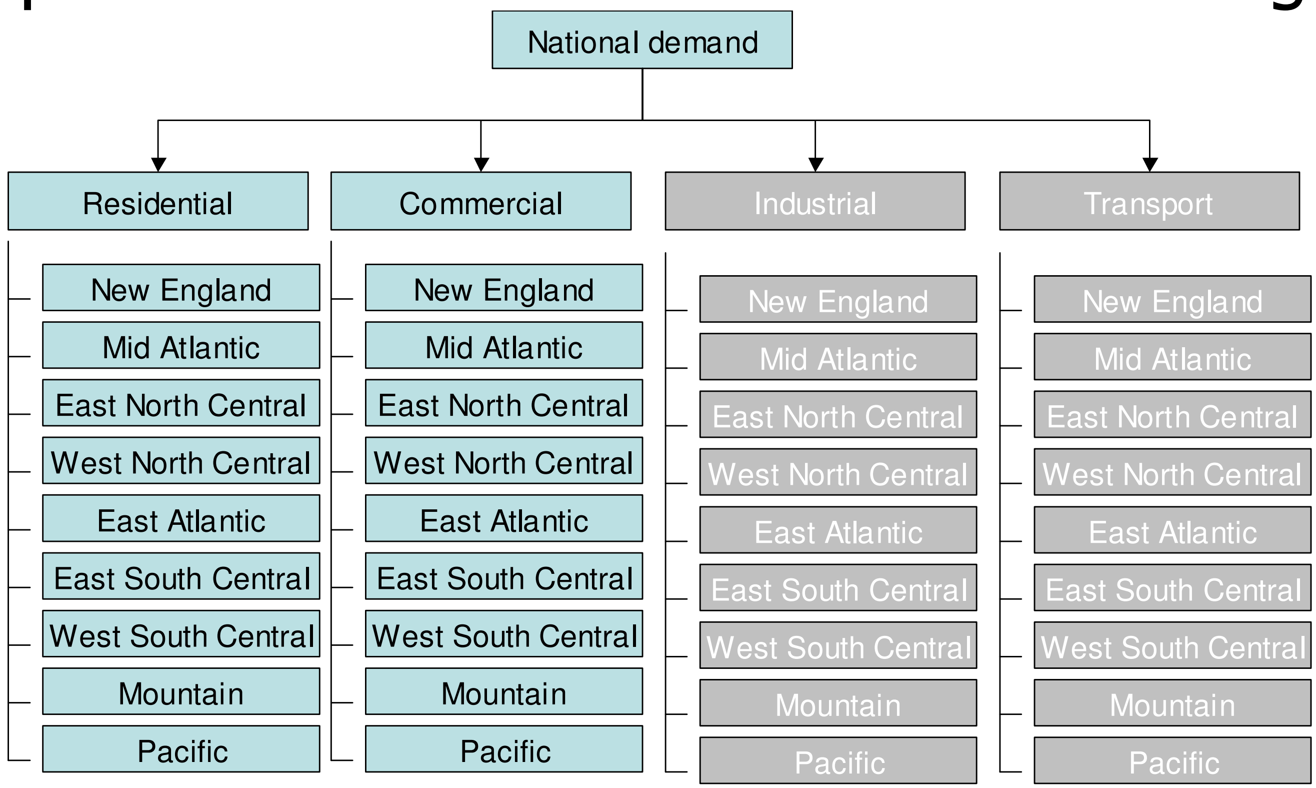
- Separate forecast for each sector



- Models are still econometric

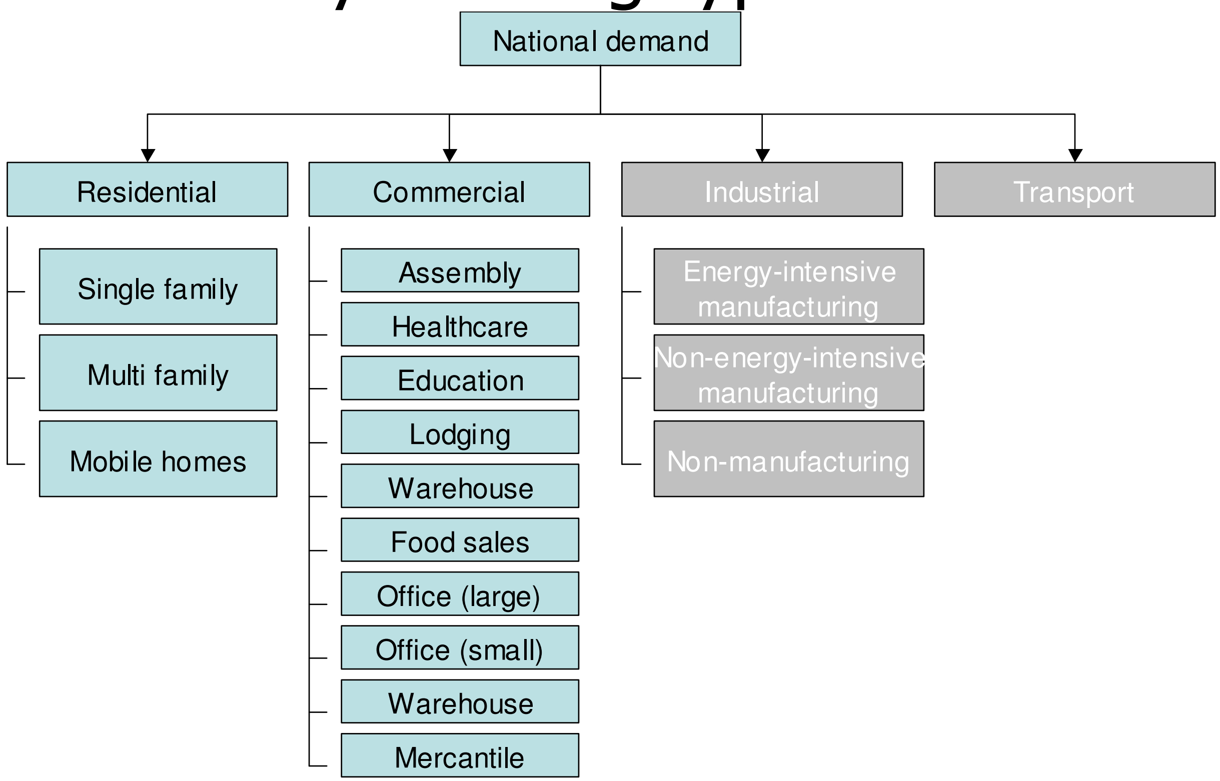
Level 3 Forecast

- Separate forecast for each sector and region



Level 4 Forecast

- Break down by building type



SEDS Summary

- Simulation environment for macro-level policy decision support tool
- Speed enables “what-if?” scenario evaluation
- Output recognizes stochastic nature of inputs

THE END

(at last!)